National Climate Change Process

SINKS TABLE OPTIONS PAPER

Land-Use, Land-Use Change and Forestry in Canada and the Kyoto Protocol

September 23, 1999

PREFACE

As part of Canada's National Post-Kyoto Climate Change Implementation Process, the National Secretariat recommended that issue-specific Tables be formed to capture the views of non-government organizations, industry and the provincial and federal departments from across Canada. The Secretariat identified a number of key issues requiring the formation of Tables, including – but not limited to: modeling and analysis, transportation, electricity, international emissions trading, credit for early action, adaptation, technology, public education and outreach, industry, forest sector, agriculture and sinks.

The Kyoto Protocol limits which types of sinks can be used to offset emissions, but allows for negotiations on what and how additional sinks can be used to meet commitments. The primary purpose, therefore, in forming the Sinks Table was to identify the state of knowledge, gaps and challenges surrounding the complex issue of sinks and sources in forestry, agriculture, and other land uses. This information is contained in the Table's Foundation Paper. In addition, the Table was tasked with recommending a course of action to ensure that the necessary information and analyses were available to support the ratification and implementation of the Kyoto Protocol.

This Sinks Table Options Paper builds on the studies and analyses undertaken over the last 15 months, as well as the information contained in the Table's Foundation Paper, which was prepared by the Table in the fall of 1998. Given the fact that many uncertainties – both analytical and political – remain, the Table has recommended a limited number of immediate sink enhancement measures, and is recommending that additional analytical studies be carried out.

This Options Paper report was prepared for the National Sinks Table by Environment Canada (Pollution Data Branch) with contribution from the Canadian Forest Service of Natural Resources Canada and a variety of authors.

While a consensus of views was attempted, the views expressed in this paper are not necessarily those of the Government of Canada, nor the organizations or provincial governments represented on the Sinks Table.

ACKNOWLEDGEMENTS

The Co-Chairs wish to acknowledge the grateful participation and efforts of all members of the Sinks Table who volunteered their time, energy and expertise. In addition, we are especially indebted to some members of the Forest Sector Table of Environment Canada and the Canadian Forest Service staff in undertaking much of the work of the Table and the development of this document. In particular, we wish to express a warm appreciation for their work to Marie Boehm, Darcie Booth, Pascale Collas, Muriel Constantineau, John Hastie, Henry Hengeveld, Tony Lemprière and Jim Patterson. Pascale Collas of Environment Canada was responsible for the coordination of the report preparation, and without her efforts and diligence, this report would not have come together. Finally, we would like to acknowledge the work undertaken by the many consultants, who along with the rest of us, worked under extremely short timelines.

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EXECUTIVE SUMMARY

INTRODUCTION

The continuing international negotiations and uncertainties surrounding land-use, land-use change and forestry (LULUCF) issues constitute the primary rationale for the creation of the National Sinks Table. Canada needs to be able to estimate, with a degree of certainty, the contribution that the land-use, land-use change and forestry activities currently recognized in the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), as well as any additional activities, can make to help meet its emission reduction target.

The Table was asked to first identify the state of knowledge, gaps and challenges surrounding the issue of biological sinks as they relate to forestry and agriculture and any other sectors that may be identified. Second, the Table was mandated to furnish technical input and advice to governments to inform decisions on the ratification and implementation of the Kyoto Protocol as it relates to sinks. The Table only addressed CO_2 sinks and not other greenhouse gases, although these are also relevant to land-use, land-use change and forestry.

This Options Paper reflects the discussions and current knowledge on sinks of the members of the Sinks, Forest Sector and the Agriculture and Agri-Food Tables, and is based on input from experts in the forestry, agriculture and wetlands areas. It is intended to raise the level of understanding of the sinks issue among stakeholders and policy makers in Canada by the provision of technical background and analytical information, while not intending to duplicate what was already covered in the Sinks Table Foundation Paper. The work of the Table, which confirmed that sinks are very important to Canada, contributed significantly to fostering discussions among various groups and players across the country.

LAND-USE, LAND-USE CHANGE AND FORESTRY AND THE KYOTO PROTOCOL

The UNFCCC, adopted in 1992, states that:

> *"Each Party shall... limit its anthropogenic emissions of greenhouse gases and protect and enhance its greenhouse gas sinks and reservoirs".*

The UNFCCC defines a sink as "*any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere.*" Currently, photosynthesis — a natural biological process — is the only process considered by the FCCC to act as a sink by removing carbon dioxide from the atmosphere. However, anthropogenic land-uses and land-use changes can also directly alter the size and rate of natural exchanges of greenhouse gases (GHG) among terrestrial ecosystems, the atmosphere and the ocean. Due to the dominating influence of natural forests and large areas in agriculture in Canada, the sinks issue and the inclusion of land-use, land-use change and forestry is of particular interest to our country.

International Negotiations

The arguments for the inclusion of land-use, land-use change and forestry sinks in the Kyoto Protocol stemmed from the fact that the UNFCCC recognizes them, and that the best incentive to protect and enhance sinks is to have them part of a legally binding agreement.

The Kyoto Protocol compromise was an agreement to include some land-use change and forestry activities, undertaken after 1990, that affect sinks — namely reforestation, afforestation and deforestation (RAD). These would be added to or subtracted from Parties gross emissions when assessing compliance over 2008-2012 and would be measured as verifiable changes in carbon stocks. If there is an increase in C stocks between 2008-2012 as a result of RAD activities undertaken after 1990, then the average amount of C removals during the period will be substracted from Canada's average emissions for that period. Conversely, if C stocks decline during that period, the amount will be added to

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Canada's emissions from 2008-2012. Depending on the final decision regarding how the three RAD activities will be defined, the net contribution from RAD since 1990 could be either a source or sink.

As previously noted, not all sinks are currently included under the Kyoto Protocol. However, under Article 3.4 of the Kyoto Protocol, there is provision for negotiation on additional human-induced activities resulting in emissions from sources and uptake by sinks in forests. Current rules for adding additional activities, and how they should be accounted for, therefore remain highly uncertain and are likely to remain so until at least the sixth meeting of the Conference of the Parties (CoP), to be held in late 2000 at the earliest. Activities presently under examination by Canada and other countries include the managed forest approach, carbon sequestration in forest products and agricultural soil sequestration practices (including cropland and pasture management, the conversion of marginal cropland to perennial grass and wetlands restoration).

Canada's Strategic Interests

Based on 'business as usual' estimates, Canada must reduce its net emissions by 140-180 Mt CO_2 per year over 2008-2012 in order to meet its Kyoto emissions target. Many are concerned that achieving that target only through reduction in emissions could have adverse effects on our economy and international competitiveness. Depending on how the rules are established for the treatment of sinks, sinks enhancement options could be available at lower (or comparable) costs than conventional emissions reduction methods. To realize those strategic interests, however, gaining a better understanding of the potential of each possible sink activity is warranted.

The inclusion of sinks under some negotiation outcomes could make the task of meeting the Kyoto target more onerous and expensive, rather than less expensive. Thus, Canada has a vital interest in understanding the potential contribution of land-use, land-use change and forestry under varying scenarios, advocating international rules that would allow it to take the best advantage of sinks where supported by sound science, and discouraging rules and definitions that would restrict or unduly affect Canada's flexibility in cost-effectively meeting its Kyoto commitment.

It is in Canada's best interest to continue to take a major role in developing the international modalities, rules and guidelines for reporting sequestered carbon under the Kyoto Protocol, and to ensure Canadian expertise is available to aid in future negotiations related to carbon sinks within the context of the Kyoto Protocol. To do so, Canadians must actively seek international collaboration with other countries in developing the databases, monitoring systems and models needed for such reporting, and should also be active participants in international scientific assessments such as those conducted by the Intergovernmental Panel on Climate Change (IPCC).

The 'Kyoto Forest' - A Canadian Perspective

Currently, the Kyoto Protocol does not consider the whole Canadian forest, or even a major component of it like the "managed" forest. Instead, the Protocol includes a smaller fraction of the Canadian forest known as the 'Kyoto Forest'. It is the area of forest subject to three specific forestry activities — reforestation, afforestation and deforestation (RAD) — undertaken since 1990. Thus, changes in the carbon in Canada's total forest have no bearing on Canada's efforts to meet its Kyoto commitment.

For many countries, including Canada, the Kyoto Forest represents a small fraction of their existing managed forests. By limiting activities to exclude all forests not part of the Kyoto Forest, the Protocol is not quite balanced in its treatment of sources and sinks and, therefore, fails to provide credits/incentives for good forest management practices. Canada will also have to account for a large carbon debit as a result of deforestation. It will obtain only a small credit from afforestation and reforestation, as newly planted trees will still be very young in the first commitment period (2008-2012).

Current national inventories prepared using the Intergovernmental Panel on Climate Change (IPCC) Guidelines do not reflect the boundaries of the Kyoto Forest. Therefore, new inventory methods will need to be developed to account for net emissions or removals from the Kyoto Forest, and Annex I Parties such as Canada will need to build the institutional capacity to collect the appropriate data and apply these methods.

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CARBON SEQUESTRATION OPTIONS IN FORESTRY AND LAND-USE CHANGE

Based on the work of the Table and the studies that have been conducted since its inception, there are a number of options for consideration by Ministers related to Afforestation, Reforestation and Deforestation activities. Each are summarized below. These options were developed in close cooperation with the Forest Sector Table and are consistent with those presented in their Options Paper. In fact, afforestation is the only sequestration option for which the Table conducted detailed analysis. Information with respect to reforestation and deforestation is only available in a qualitative way. All recommendations can be found immediately after this executive summary.

Afforestation

The term 'afforestation' has not yet been defined for the purposes of the Kyoto Protocol, and international agreement on a definition is not likely for several years, although it is fairly certain that the options considered here will be applicable under any likely negotiation outcome. Two possible definitions for afforestation are as follows:

1. "the planting of new forests on lands which, historically, have not contained forests" (IPCC definition); and
2. "a change in land-use that, through the establishment of a stand of trees, forms a forest"
   (a working definition submitted by Canada for the IPCC special report).

Actions that are recommended by the Table for immediate action include regional afforestation programs with native species, fast-growing plantations and increased planting of shelterbelts. As far as fast-growing species are concerned, a concerted effort to afforest 50,000 ha over five years (2001-2005) will result in 1.3 Mt CO_2 in 2010. Planting 793,000 ha over 15 years (2001-2015) in native species results in sequestration of 0.8 Mt CO_2 in 2010, though this estimate reflects considerable uncertainty in tree growth in the first few decades after planting. While we assumed that planting could start as early as 2001 at a modest level, this is an optimistic assumption and will require an immediate and intensive effort to achieve. However, delaying start-up to 2002 or 2003 significantly reduces carbon sequestration in the first commitment period.

Over the 2000-2050 period, carbon sequestration averages over 4 Mt CO_2 per year from planting traditional species. In comparison to planting larger areas in native species, fast-growing plantations are much more cost effective and result in significantly more sequestration in the first commitment period. Over a longer time period, however, fast-growing plantations have a disadvantage because the trees have much shorter lives. Annual carbon sequestration after 20 or 50 years from traditional species will be quite substantially higher (2.9 Mt CO_2 in 2020 and 7.5 Mt CO_2 in 2050) than it is in the first commitment period (0.8 Mt CO_2 in 2010) and, therefore, long-term sequestration rates should be taken into account.

One of the principal challenges of afforestation efforts in Canada is the complexity and difficulty of attracting thousands of individual landowners to allow their marginal agricultural and other land to become forested land. Involvement in afforestation is likely to proceed slowly at first, as programs and policies are implemented, financing mechanisms developed, landowners and others learn about opportunities, technical advice is developed and made available, rules for carbon accounting are developed and nursery stock is made available. It is not likely that planting will start before 2002 or 2003 in some regions, given the time needed to first obtain participation of landowners.

Determining likely rates of participation in afforestation is no easy matter and requires an assessment of the up-front costs and benefits to landowners (e.g. payments for conservation easements), future costs and benefits, and their personal preferences and goals related to current and future land-use. It is predicted that the up-front costs for afforestation will be relatively high, given the target level of afforestation in terms of area, and the characteristics of the land and landowners likely to be involved. Incentives that landowners will require may not only be financial but also could include technical assistance and information on the benefits of afforestation on their land. Involvement of other participants interested in benefits (e.g. forests products) is also likely. An intent to achieve goals beyond just carbon sequestration — such as environmental, land management goals — could be the most successful approach to the development of afforestation programs. Afforestation may seem costly relative to other actions that could be initiated in the short to medium term. However, it will prove beneficial in the longer term, but only if the action is taken now.

Afforestation actions proposed by the Sinks Table are summarized in Table S1, in which only direct planting and maintenance costs are estimated. Costs and potential benefits which have not been accounted for include: forest protection costs, afforestation program costs; the net revenue from harvesting or use of mature stands; carbon monitoring, measurement and verification costs; and the potential value of carbon credits.

Table S.1

Initiative Description	*Planting schedule*	*CO_2 Sequestration*	*Costs (1997$)*	*Cost Effectiveness*
Plant 50,000 hectares of a fast-growing tree species on private lands across Canada	10,000 ha/yr 2001 to 2005	1.31 Mt CO_2 by 2010 [1]	~$141 million in planting and opportunity costs	$22.20 /t CO_2 over 2008-2012
Plant shelterbelts on private lands in the Prairies [2]	13,000 ha/yr 2001 to 2015	0.15 Mt CO_2 in 2010, averaging 0.58 Mt CO_2 / year between 2000 and 2050	~$107 million in planting and opportunity costs	$140.7 /t CO_2 over 2008-2012 $3.70 /t CO_2 over 2000-2050
Plant block plantations on private lands in the Prairies	20,000 ha/yr 2001 to 2015	0.37 Mt CO_2 in 2010 averaging 1.43 Mt CO_2 / year between 2000 and 2050	~$214 million in planting and opportunity costs	$114 /t CO_2 over 2008-2012 $3 /t CO_2 over 2000-2050
Plant block plantations on private lands in B.C.	13,000/yr 2001 to 2015	0.15 Mt CO_2 in 2010, averaging 0.70 Mt CO_2 / year between 2000 and 2050	~$85 million in planting and opportunity costs	$452.5 /t CO_2 over 2008-2012 $2.40 /t CO_2 over 2000-2050
Plant block plantations on private lands in Eastern Canada	15,000 ha/yr 2001 to 2015	0.22 Mt CO_2 in 2010, averaging 1.37 Mt CO_2 / year between 2000 and 2050	~$157 million in planting and opportunity costs	$144.9 /t CO_2 over 2008-2012 $2.30 /t CO_2 over 2000-2050
Total		***2.2 Mt CO_2 in 2010***	***~$704 million in planting and opportunity costs***	***Not applicable***

Notes:

[1] Harvesting of fast-growing plantations will begin either at the end of the first commitment period or immediately afterward (2012 to 2015), raising the issue of the time path of carbon credits and potential debits that will offset some of the credits as early as the beginning of the second commitment period.

[2] This action builds on existing interest and programs to promote shelterbelts for many decades in the Prairies, for soil conservation and farmyard windbreaks, with much of the planting supported by the Prairie Farm Rehabilitation Administration (PFRA).

Reforestation

Data and time limitations made it impossible for the Table to develop estimates of CO_2 sequestration and cost effectiveness associated with reforestation activities. Furthermore, there is currently political and scientific debate over the definition of reforestation, as it is still to be negotiated internationally under the Kyoto Protocol. There are two distinctly different interpretations that are critical to any estimates of future potential. The IPCC greenhouse gas emission inventory guidelines defines reforestation as the "*planting of forests on lands which have, historically,*

previously contained forests but which have been converted to some other use." The United Nations Food and Agriculture Organization (FAO) defines reforestation as the establishment of a tree crop on forest land. In addition, Canada had proposed a working definition of reforestation: "*a land-use practice that, through the re-establishment of a stand of trees, forms a forest.*" The key issue is whether the re-establishment of trees after harvesting (i.e. regeneration) is included under the Protocol as reforestation.

If the IPCC definition is adopted, then there are essentially no "forestry" activities under Article 3.3. of the Protocol, which refers to direct human-induced "land-use change and forestry activities of afforestation, reforestation and deforestation." Reforestation will in fact be "re-afforestation", as most areas in Canada currently available for tree planting were at one time "historically" forested.

If the FAO definition is adopted (i.e. regeneration after harvest), then Canadian "business as usual" reforestation estimates obtained by the Tables for 2010 are in the -2 (source) to 13 (sink) Mt of CO_2 per year range, depending upon carbon stocks components (all above- and below-ground biomass and soil are included in the first case; the second case includes above-ground biomass only). Which component of C stocks will be counted is critical since there are indications that changes in below-ground and soil C cause areas to be a net source for 10 to 20 years after harvest.

Under the 'regeneration after harvest' definition, two elements of regeneration strategies that could increase the sequestration potential are species selection and density management. While current guidelines and research are aimed at maximizing commercial volumes at harvest, some research indicates that significant biomass gains can result from such modifications in planting or spacing regimes.

In addition to species selection and density management, increased planting instead of natural regeneration and seeding after harvesting can also increase carbon sequestration. Currently, forests in Canada are regenerated after harvesting by either planting (45%), seeding (5%) or natural regeneration (50%). By planting, trees generally reach maturity 10 to 13 years earlier than naturally regenerated stands. Planting also offers the opportunity to use genetically enhanced seedlings, or, in readiness for future temperature changes due to climate change, species more suited to the site.

Overall, it is in Canada's interest to anticipate upcoming international negotiations under the Kyoto Protocol and explore the potential options for enhancing sequestration through reforestation.

Deforestation

International negotiations on the definition and interpretation of deforestation under the Kyoto Protocol will be an important determinant of what types of deforestation activities will be counted as a source of CO_2 emissions. The UNFCCC Secretariat has suggested that deforestation might be defined as "*the conversion of forest land to other land-use.*" Refinements of this definition that have been suggested raise the issue of whether the definition should be land-use or land-cover based.

Canada had suggested to the IPCC a working definition of deforestation as "*a change in land-use that removes a forest.*" This definition would include forest conversion for permanent land-use changes such as agriculture and rangeland activities, as well as development of permanent infrastructure, such as a highways. However, it would exclude areas that did not change the land-use, such as construction of forest management access roads. As for the other LULUCF activities, international agreement on the definition of deforestation may not be reached until CoP6 or later.

Deforestation in the first commitment period (2008-2012) will be counted as a *source* of CO_2 emissions. As such, deforestation represents a liability, in the sense that emissions from deforestation will increase the overall level of emissions of Canada's business-as-usual scenario above the 1990 baseline level. It is critical to understand that even a small amount of deforestation can be significant, as the debits are relatively 'instantaneous', and cannot easily be offset by credits due to afforestation or reforestation.

There is limited information available in Canada on the current and recent (since 1990) extent and spatial location of deforestation as this information is not explicitly monitored by federal or provincial agencies. It is estimated that

Canada's major sectors (agriculture, forestry, urban development, transportation, recreation, mining and petroleum, and the electrical industry) contribute to a total of 9 to14 Mt of CO_2 loss due to deforestation. Of these sectors, forestry (4 Mt) and agriculture (2 to 6 Mt) are the most significant contributors to deforestation, although it is dependant on definitions. Other estimates show a 3 to 19 Mt CO_2 range for total annual deforestation. These estimates include above-ground biomass only. However, it is unlikely that all of these sectoral deforestation activities will be covered under the definition of deforestation to be negotiated under the Kyoto Protocol.

The identification of policies to reduce deforestation will be an important part of Canada's overall climate change strategy. Policies will need to be balanced against other economic and social objectives (e.g. regional economic development and employment). A range of policy options (e.g. taxation incentives, financial assistance, government regulations, and education and promotion policies) needs to be evaluated in order to identify the most cost-effective mix of voluntary and/or non-voluntary measures to reduce deforestation.

Currently, there is a critical information gap on deforestation. Further analytical needs include information on the spatial and temporal forestry characteristics of the forests that are deforested, and the subsequent carbon release. Deforestation estimates may be improved through further research, such as the use of remote-sensing technologies combined with statistical surveys. Further research into the design and implementation of effective policies to reduce deforestation is also needed, given the large range of activities and sources from different sectors that currently contribute to deforestation in Canada. A key requirement for meeting Canada's emission reduction commitments under the Kyoto Protocol will be to develop policies to reduce deforestation without unfairly limiting natural development activities as well as measurement and reporting tools to monitor changes in deforestation activities and associated CO_2 emissions.

Other Forest Management Activities and The Managed Forest

As a result of Article 3.4 of the Kyoto Protocol (provision for negotiation on additional human-induced activities resulting in emissions from sources and uptake by sinks in forests), various forest management activities have been proposed that could enhance carbon sinks in forests. These include thinning, fertilization, fire and pest protection, and reduced regeneration delay through planting and seeding. However, increasing the number of activities accepted under the Protocol would further complicate the methodology for accounting for verifiable changes in carbon stocks that could be attributed to these specific activities. Further, the impact of these management practices is both species-specific and site-specific and there is no one strategy that will fit all forest types and all regions or countries.

Fire protection is not likely to be considered as an additional forestry activity under the Protocol for a variety of reasons, including methodological issues. Fire impacts are highly variable from year to year and accepting responsibility for protection means running the risk of major carbon loss during significant fire years, likely to become more common under projected climate change.

An alternative approach is the so-called "managed forest approach" whereby a full accounting of changes in carbon stocks is conducted within that area, without distinguishing between the various management practices. The managed forest approach is consistent with encouraging the protection and enhancement of carbon sinks and reservoirs, a key objective of the Framework Convention on Climate Change. Further, the approach would be more balanced in considering both removals from sinks and emissions from sources than the current provisions of the Kyoto Protocol (i.e. RAD) and would contribute to additional benefits (e.g. employment, forest growth and environmental benefits).

Key uncertainties related to a managed forest approach, however, include the definition and extent of the "managed forest", the accounting rules, and the measurement and verification methodologies (e.g. ground measurement versus modeling). Of major consequence is the definition of Canada's own managed forest, with current estimates ranging from approximately 30 to 55% of Canada's roughly 417 million hectares of forest.

In addition, Canada has a very high natural disturbance regime (i.e. fires, pests) compared to most countries and Canada's forests as a whole are thought to be a net source of CO_2. Since the Kyoto Protocol focuses upon anthropogenic emissions only, emissions from natural disturbances are not currently considered part of Canada's emission target. It is

unclear how emissions from forest fires within the managed forest would be handled if the Protocol moves to a managed forest approach.

Further, the lack of large-scale nationally accepted growth and yield information creates a problem for estimating potential gains from the managed forest under the Protocol. More analysis is needed on this approach, and negotiations should proceed with caution until the net impacts for Canada are determined.

If the managed forest was included under the Protocol instead of (or in addition to) RAD, the carbon stored in forest products would need to be considered as well. Currently, international forest industries are actively supporting the inclusion of existing forests and forest products in carbon accounting for meeting Kyoto targets. There are actions that could be taken to specifically affect the carbon stocks of forest products. Whether Canada would obtain a benefit or not from expanding forest product carbon pools, given its export orientation, would depend upon the measurement and accounting rules and systems.

AGRICULTURAL SOILS CARBON SEQUESTRATION STRATEGIES

Agricultural soil sinks are not currently included in the Kyoto Protocol and many countries are not yet supportive of their inclusion. This is presumably because of a lack of confidence and some uncertainties in relation to the estimates, and the fact that Parties — unsure of the state of their soils — have not reported on them. Not all Parties are convinced that they should be included under the Kyoto targets. To some, there still remains considerable doubt that Parties are able to measure and monitor "verifiable changes in soil carbon stocks".

However, given its importance as a key indicator of soil quality, the measurement of carbon in agricultural soils has been a routine practice for many years. The Sinks Table, along with soil carbon experts in the U.S., Canada and elsewhere, believe that verifiable monitoring and reporting systems for agriculture are feasible and should not be seen as insurmountable barriers to gaining wider acceptance of agricultural carbon sinks.

Countries with the largest absolute potential for carbon sequestration through implementation of best soil management practices are, in order, the U.S., China, India, the Russian Federation, Australia and Brazil (all greater than 90 Mt CO_2/year). This includes all practices on all agricultural lands, including degraded lands, irrigation control, etc. The U.S. potential ranges from 275 to 760 Mt CO_2/yr for 2010, mostly from conservation tillage and residue management. It was also found that for most developing countries with relatively low emissions, C sinks could offset from 20% to more than 100% of industrial emissions, although the potential is very much dependant upon the rate of participation. By demonstrating to countries the sequestration potential that exists on their lands, support could be gained for the inclusion of soils sinks in the Protocol.

Enhancement strategies that could be implemented to realize the potential of Canadian agricultural soil carbon sinks include conservation practices on croplands (e.g. reduced/no tillage and reduced summerfallow), pasture management, conversion of marginal croplands to perennial grass and conservation of wetlands riparian areas.

Using the CENTURY modeling tool forecasts, it is predicted that Canadian agricultural croplands will change from a *net source* of 1.6 Mt CO_2 (1996 estimate) to a *net sink* of 1.6 Mt of CO_2 by 2010, if the current trends in farm practices, such as adoption of no-till, continue without additional incentives. Work is currently under way to refine and improve the reliability of the CENTURY model by correcting some of its weaknesses.

Different results were obtained, based on experts' judgement, for potential annual sequestration rates associated with each of the four agricultural soil carbon sink enhancement strategies, as summarized in the Table S.2 on the following page.

Table S.2: Summary of Potential Agricultural Soil Carbon Sequestration Practices

Strategy	Annual Sequestration Rate 2008-2012 Mt CO_2	Annual Sequestration Rate 2013-2017 Mt CO_2	Cost \$/tonne CO_2 Range (mean) *
1. Conservation Practices on Cropland	**18.3**	**18.1**	**0.60-6.33 (4.26)**
2. Pasture Management	**0.7**	**2.5**	**8-10 (9)**
3. Convert Marginal Cropland to Grass	**2.2**	**2.2**	**3.35**
4. Wetland Restoration	**2.9**	**2.9**	**N/A**
Total:	**24.1**	**25.7**	**N/A**

* The cost figures, which are a compilation of highly scattered information, are given as an indication only.
N/A – not available

The first enhancement strategy – encouragement of conservation practices on cropland, including no till and reduction in conventional summerfallow – offers the most potential in both the first and second commitment periods. Furthermore, it is potentially one of the more cost-effective strategies. The potential offered by this strategy is based on the fact that innovative and early adopting producers have already embraced conservation practices.

The figures provided above are probably an overestimation of the real sequestration potential, even under the same adoption rates, since they represent a "gross" sequestration potential. Other croplands that are not subject to conservation practices may well be sources of CO_2 (e.g. conventional tillage and other practices). Potential associated increases or decreases in CH_4 and N_2O emissions also need to be factored into the equation and further work is required to accomplish this. In fact, the potential sequestration on croplands ranges from around 2 to 18 Mt CO_2 for the first commitment period, if CENTURY projections for 2010 (1.6 Mt CO_2 per year) are included in the spectrum of estimates.

As far as pasture management is concerned, it includes such practices as pasture fertilization and intensive pasture grazing management. Sequestration opportunities for the 4.3 million ha of pastures in Canada are estimated to be 0.7 and 1.0 Mt CO_2 per year for the first and second commitment periods, respectively. Current programs encourage improved methods of pasture management and are provincial government-led programs, in alliance with local grazing clubs and provincial stockgrower associations.

Conversion of marginal cropland to perennial grass includes land which was recently converted in the federal Permanent Cover Program ("existing" grassland), and a similar amount of land, which is anticipated to be converted to grass in the future ("new" grassland). This group of practices has the potential to sequester up to 2.2 million tonnes of CO_2 per year during the first commitment and second commitment periods. This would require an adoption rate of 50,000 ha /year for 10 years from a base of about 500,000 ha. of marginal cropland already converted to grass.

The enhancement of wetlands through the restoration of margins (the 'riparian zone') around Prairie potholes is similar to conversion of marginal cropland to permanent vegetation. Ducks Unlimited estimates that up to one million hectares of riparian zone could be restored on the prairies. This would bring an opportunity to sequester 2.9 Mt CO_2/yr in both the first and second commitment periods, assuming an adoption rate of 100,000 hectares per year for 10 years.

Agricultural soil sequestration could offer crop producers greater revenue, and potentially lower input costs resulting from lower fuel use, as well as more efficient use of fertilizers. The overall impact of agricultural soils conservation practices on the environment is a healthier, more productive soil that is less subject to wind or water erosion, and more sustainable agroecosystems and environment.

The Sinks Table has been working closely with the Agriculture Table to exchange relevant information. An addendum to the Sinks Table Options Paper will be produced that will incorporate the results of sequestration scenarios modeling conducted by the Agriculture Table.

MEASUREMENT, MONITORING AND VERIFICATION OF CHANGES IN CARBON STOCKS

Article 3 of the Kyoto Protocol emphasizes that national reports on sources and removals by sinks of greenhouse gases resulting from human-induced land-use change and forestry activities must be transparent and verifiable, using modalities, rules and guidelines yet to be decided upon. Efforts to gain acceptance of other potential sinks, such as the managed forest and carbon in agricultural soils, will be dependent on the availability of such credible data. Available data and our present understanding of carbon flux processes are as yet inadequate to provide a credible reporting system. A number of generic research priorities exist and include understanding soil composition and decomposition processes, response of carbon fluxes to forest and agricultural management practices, global and regional environmental change and disturbances, and scaling up processes to ecosystem and landscape level.

Forestry Carbon Stocks

The reporting requirements of the UNFCCC and Kyoto Protocol point out the urgent need for a national forestry related carbon (C) accounting and reporting system whose main fimction would be to track, store and report information on changes in C stocks for three areas: the Kyoto Forest, the managed forest and the total forest area. Details of reporting requirements will be dependent on the outcome of future negotiations on the implementation of the Kyoto Protocol, which will determine the extent of the Kyoto Forest, the types of additional activities and the C pools that need to be tracked. The main components of a national accounting system are data acquisition, storage, models, parameter databases, reporting tools and verification. A system would need to be sufficiently flexible to adapt to new information and needs, and maximize information flow.

Agricultural Soils Carbon Stocks

As per the IPCC Guidelines for National Greenhouse Gas Inventories, reporting to the FCCC requires that annual estimates of CO_2 fluxes be determined for agricultural soils. So far, Canada has been reporting the results of the CENTURY model. The acceptance of agricultural soils as a carbon sink in the Protocol is contingent upon the development of a verifiable measurement and monitoring framework to enable an accurate determination of net changes in carbon storage in soils. To arrive at verifiable estimates of changes in soil carbon, a monitoring and measurement framework should consist of four major elements:

1. predictive tools (e.g. CENTURY model, rule-based and/or other soil organic matter models);
2. land-use and management data;
3. soil/climate database; and
4. scaling-up techniques (site-specific model predictions of soil carbon, scaled to a regional or national level).

A very preliminary gross estimate cost for the development and implementation of the entire measuring and monitoring framework for carbon stocks in soils is $12 million to be spent between 2000 and the end of the first commitment period in 2012. The largest cost component is associated with the development of a rule-based system and refinement of a modeling tool such as the CENTURY model, with a very preliminary estimate of about $8.5 million.

WETLANDS CONSERVATION

Canada's wetlands cover approximately 14% of Canada's land surface and contain over 150,000 Mt of carbon, approximately 60% of Canada's carbon stock. Should agricultural soil management be confirmed as an accountable sink category and/or should C stocks encompass the soils pool, one could expect that Canada would be accountable for some wetlands, since they are such prominent components of both forest and agricultural landscapes. The step beyond that, the inclusion of wetlands in the agreement, would provide an opportunity for managing their capability to enhance carbon sequestration while sustaining other valued ecosystem functions.

Attributes of wetlands, which may render them net sinks, include:

- high primary productivity (ensuring abundant organic carbon available for sequestration);
- reduced decomposition (due to the anaerobic nature of wetland sediments and colder northern climates);

- reduced CH_4 emissions (due to CH_4 oxidation in the aerobic environment of algae and emergent vegetation); and
- low nitrous oxide emissions due to continually water-logged soils and low nitrate levels in many wetlands.

The restoration of actual wetlands basins through re-establishment of aquatic vegetation, as well as soil C restoration in the riparian zones and uplands that may be cultivated, would be part of an integrated management program. However, the current state of scientific knowledge does not warrant considering wetlands as distinct carbon sinks under the Kyoto Protocol at this point in time. Wetlands degraded through direct human activities and/or climate change impacts could become an emissions source. Research efforts and studies need to be undertaken to properly assess wetlands management as potential carbon sinks.

CARBON SEQUESTRATION AND THE EMERGENCE OF CARBON AS A GLOBAL COMMODITY

A domestic emissions trading scheme could be valuable if designed in a way this stimulates adoption of carbon sequestration by forest managers and farmers. Under the Kyoto Protocol, joint GHG mitigation activities may be undertaken through the three cooperative Kyoto Mechanisms: *Annex I Joint Implementation* (JI), the *Clean Development Mechanism* (CDM) and *International Emissions Trading* (IET). The current *Activities Implemented Jointly* (AIJ) pilot phase enables Parties to undertake cooperative efforts to reduce emissions by sources and enhance removals by sinks. As part of the National Process on Climate Change, a separate Table has explored in-depth the use of the Kyoto mechanisms.

Annex I Joint Implementation (JI)

Annex I JI, outlined in Article 6, enables Annex I Parties to transfer to, or acquire from, other Annex I Parties the emission reduction units (ERUs) produced by any GHG mitigation projects that are *additional* to any that would otherwise occur. Annex I JI projects do not seem to be explicitly constrained by the limitations on sink activities specified in Article 3. However, if the restrictions on sinks activities under Article 3 do not apply to Annex I JI projects, then it is possible for Annex I Parties to claim GHG benefits for sinks activities undertaken outside of their borders that would not qualify if they were undertaken within their borders. There may be very little incentive for an Annex I Party to host an Annex I JI project whose activities do not meet the requirements under Article 3.3, if it is not additional to what would have otherwise occurred.

Clean Development Mechanism (CDM)

The CDM, outlined in Article 12, enables developing countries (i.e. countries outside of Annex I) to host projects that contribute to their sustainable development goals and reduce GHG emissions, and to trade the resulting certified emission reductions (CERs) to Annex I Parties. Annex I Parties can then use the CERs to meet a portion of their target. Like Annex I JI projects, CDM projects must be additional to any that would otherwise occur. CERs can be awarded for projects starting in the year 2000.

Carbon Trading

Article 17 of the Kyoto Protocol enables Annex I Parties to trade emissions amongst themselves for the purposes of fulfilling Article 3 commitments (targets). These parts of assigned amounts, often referred to as Assigned Amount Units (AAUs), are subtracted from the assigned amount of the Party that is selling the AAUs and added to the one buying them. The boundaries of the 'Kyoto Forest' will affect the supply of Assigned Amount Units (AAUs) that may be traded internationally by determining both what Canada will have available to sell to other Annex I countries and what will be available for Canada to buy from other Annex I countries.

Under a possible domestic emissions trading regime, Kyoto sinks could be best covered under — although not limited to — a credit creation, project-based system whereby credits or offsets would be created above a pre-determined baseline. If a coverage of sinks broader than those which are or could be included in the Protocol was allowed, a Party would give away credits to "non-Kyoto-eligible" activities.

The supply of emission reduction units (Annex I JI) and certified emission reductions (CDM) that may be acquired by Canada will be influenced by the eligibility of sink projects under Article 6 and Article 12 of the Protocol (i.e. whether sinks are included in the CDM and whether the coverage in JI and the CDM is broad [beyond reforestation, afforestation and deforestation]). Also, if measurement, monitoring, verification and certification requirements are not too onerous, there is likely to be significant interest in developing sink projects in other countries.

Accounting and methodological issues associated with, although not necessarily specific to, sequestration projects and trading include the definition of baselines, the avoidance of potential leakage outside project boundaries, the permanence of sinks and the transferability of carbon units between the various types of project and mechanisms. Extensive negotiations will be required before Annex I JI, the CDM, and Carbon Trading can be put in operation. However, trading in advance markets has already started, as companies begin to learn how the mechanisms may work.

CONCLUSIONS

Some important conclusions can be drawn from the work of the Table. The Table recognizes that forestry and agricultural sinks should play a role in a National Implementation Strategy. Depending upon the outcome of international negotiation on definitions of reforestation, afforestation and deforestation (RAD), the net "business as usual" contribution from these activities from 2008-2012 could be either a substantial source or sink. These definitions are expected to be resolved, at the earliest, at CoP6 in late 2000. Depending upon whether reforestation is defined as re-afforestation (a change in land use) or as regeneration after harvest (no change in land use), the net RAD contribution under a business as usual scenario is estimated to range from a source of 3 to 19 Mt CO_2 or from a source of 21 Mt to a sink of 10 Mt CO_2 during the first commitment period, respectively. Estimates are not available for the second period, but assuming deforestation levels remain constant, the business as usual would be a source of 3 to 19 Mt or from a source of 5 Mt to a sink of 22 Mt CO_2, respectively.

Because of large data gaps and basic information needs, estimates are incomplete and uncertain and, therefore, refinements and further research are necessary. The Table had difficulty in its analysis owing to the high uncertainties resulting from the unresolved international negotiations on methodological issues related to land-use, land-use change and forestry. At present, quantitative estimates of the potential net contribution of emissions from sources and uptake from sinks for Canada can only be presented as a range of possible outcomes. Currently, there is no real "sinks model" for the three forestry activities included under the Protocol, namely reforestation, afforestation and deforestation. Generally, costs, emissions/removals associated with the land-use, land-use change and forestry activities cannot be rolled-up easily with the emission reduction activities associated with other sectors. Thus the Sinks Table recommends caution in trying to interpret the estimates provided in this report and using them in the national roll-up and modeling exercise. Considerable investment into research and information is required now, so that Canada will be able to provide accurate and verifiable estimates of the change in carbon stocks when required and to provide guidance to negotiators.

The work of the Table, in conjunction with the Forest and Agriculture Sector Tables, has made it clear that sinks are very important to Canada. It is therefore in our interest to develop both an international negotiating strategy and a National Implementation Strategy, keeping in mind the role that land-use, land-use change and forestry can and will play.

RECOMMENDATIONS

Sinks and the Kyoto Protocol

Recommendation 2.1: relevant government departments should encourage their scientists and technical experts to undertake the research priorities identified in close collaboration with peers within the international community, and to use expertise appropriately in future negotiations related to carbon sinks within the context of the Kyoto Protocol.

Land-Use Change and Forestry

Recommendation 3.1: an afforestation program to plant about 50,000 ha using fast-growing tree species should be implemented immediately as a category 1 measure.

Recommendation 3.2: afforestation programs to plant about 800,000 ha in block plantations and shelterbelts using traditional tree species should be implemented immediately as part of category 1.

Recommendation 3.3: policies to reduce deforestation should be part of Canada's post-2000 strategy (category 2) since emissions from deforestation from 2008-2012 must be added to Canada's target.

Recommendation 3.4: policies to encourage modification of reforestation methods to increase carbon sequestration on areas reforested since 1990 should be considered for inclusion in a post-2000 strategy (category 2).

Recommendation 3.5: policies should be put in place to promote activities in the managed forest which enhance carbon sequestration.

Recommendation 3.6: there is a high priority to continue to improve our understanding of the causes, location and extent of deforestation, and ways to reduce its impact.

Recommendation 3.7: there is a very high priority to determine the implications for Canada of including the managed forest and storage of carbon in forest products in the Protocol.

Recommendation 3.8: investigate the carbon sequestration and energy-saving impacts of urban forestry.

Recommendation 3.9: improve information on tree growth and yield, and changes in all carbon pools over time.

Recommendation 3.10: determine carbon sequestration impact and costs of forest management activities on forest carbon pools over time.

Recommendation 3.11: improve information on the impact and cost of actions to modify carbon storage of carbon in forest product carbon pools, and their links to on-site carbon storage in all pools over time.

Recommendation 3.12: determine the potential effect of future climate change on predictions of carbon sequestration through activities proposed in recommendations 3.1 to 3.5.

Recommendation 3.13: governments should clearly state ownership policies regarding ownership of carbon sequestered.

Recommendation 3.14: improve information on the economic incentives needed for afforestation to take place.

Agricultural Soils

Recommendation 4.1: conservation practices on cropland, pasture management, conversion of marginal cropland to perennial grass, and wetland restoration strategies should be considered further as potential

prospective measures that could play a role in Canada's strategy for reducing greenhouse gases (Category 2). Policy development, in particular to build regional or provincial alliances, could commence in 2000.

Recommendation 4.2: all programs that directly or indirectly encourage carbon sequestration in agricultural soils should be maintained. Before existing extension programs are eliminated, they should be audited to determine if they are valuable in sequestering carbon.

Recommendation 4.3: the linkage of the wetland restoration with the conservation practices on cropland, pasture management and conversion of marginal cropland to perennial grass strategies should be taken into account.

Recommendation 4.4: the implementation of the strategies should be on a national basis, recognizing that the available agricultural land base and climate in each province or region will limit the contribution to the soil carbon sink. Program funding could be on the basis of potential for carbon sequestration or number of hectares.

Recommendation 4.5: the federal and provincial governments should review all existing policies, which could affect the soil carbon sink enhancement strategies.

Recommendation 4.6: conduct research on nitrous oxide and methane emissions related to the four strategies noted above. Determine whether there are additional emission reductions or lower net carbon sequestration resulting from the effects of the five strategies on all greenhouse gases. Include fuel use, and nutrient management effects.

Recommendation 4.7: determine and refine new equilibrium levels and the carbon sequestration potential resulting from the four strategies.

Recommendation 4.8: conduct research to evaluate the economic benefits of each strategy, and identify practices that best fit each agricultural region of Canada.

Recommendation 4.9: governments should clearly state ownership policies regarding ownership of carbon sequestered in agricultural soils.

Measurement, Monitoring and Verification

Recommendation 5.1: a steering committee composed of governments' representatives and stakeholders should be established and provided with adequate commitment and funding, to take responsibility for carrying through with implementing the forest C accounting system. Such a committee should ensure that the reporting system employs methods and models that are meeting the requirements of the verification process, once defined by the international negotiations.

Recommendation 5.2: a steering committee composed of governments' representatives and stakeholders should be established and provided with adequate commitment and funding, to coordinate the development and implementation of the agricultural soils carbon stocks measurement, monitoring and verification framework.

Wetlands

Recommendation 6.1: continue to consider wetlands as a potential Kyoto sink, in particular through the organization and coordination of science and policies relevant to such sinks.

Recommendation 6.2: develop a central focus for related research in Canada to properly assess, through focused workshops, the current state of knowledge and research priorities relevant to wetlands management as potential carbon sinks. One option for achieving this goal is to establish a wetlands research node under the BIOCAP program of Canadian universities.

1. INTRODUCTION

1.1 Table's Mandate and Scope of the Options Paper

The continuing negotiations and uncertainties surrounding land-use, land-use change and forestry (LULUCF) issues constitute the primary rationale for the creation of the National Sinks Table. The primary purpose of the Table has been to identify the state of knowledge, gaps and challenges surrounding the issue of biological sinks as they relate to forestry and agriculture and any other biological sinks that may be identified. In addition, the Table has also been mandated to provide technical input and advice to governments to ensure that the necessary information and analyses are available to support a decision on the ratification and implementation of the Kyoto Protocol as it relates to sinks.

The international negotiations on LULUCF are continuing and will be a slow, complex and ongoing process for a number of years. Decisions made internationally will have critical implications for Canada's domestic greenhouse gas strategy. Despite a continuously uncertain negotiating environment, Canada must be able to estimate — with a fair degree of certainty — the contribution that the land-use, land-use change and forestry activities currently in the Agreement can make to help meet its emission reduction target along with any additional candidates.

The work on LULUCF by the Sinks Table and others cannot be done in isolation of the ongoing international work. Given the fact that not all sinks are included under the Kyoto Protocol, particularly those associated with agricultural soils, coupled with the fact that no decisions will be taken until at least the sixth Conference of the Parties in the year 2000 (if not later) on whether additional sinks will be included, the methodological work that the Sinks Table has initiated must continue. In fact, because of the outstanding uncertainties surrounding this issue, any national strategy adopted must be cognizant of this and factor it in.

This Options Paper reflects the discussions and current knowledge of this issue of the members of the Sinks, Forest Sector and the Agriculture and Agri-Food Tables. It is based on input from experts in the forestry, agriculture and wetlands areas. The Sinks Table believes that this paper will raise the level of understanding of the sinks issue among stakeholders and policy makers in Canada by providing technical background and analytical information. With this Paper, there is no intention to reproduce what is already in the Foundation Paper (National Sinks Table, 1998). The reader may want to refer to the Foundation Paper for additional information.

The Table commissioned over 15 studies since December 1998, as listed in Appendix B — some in conjunction with the Forest Sector Table. These formed the knowledge base behind this Paper. The Options Paper provides an update on the international negotiating dynamics and analyzes draft options for enhancing sequestration in the forest sector. Given time and resource limitations, as explained further in section 1.2, it was not feasible to evaluate all possible actions to enhance sequestration in the context of the Protocol, especially in the areas of agriculture and wetlands conservation, where general strategies are presented as opposed to actions or options. In most cases, the information is only provided in a qualitative way. Finally, and most importantly, in the Table's view, the Paper highlights the remaining difficulties with respect to LULUCF, and lays out the path for the development of a measuring and verification system for emissions and removals, and for further research and studies.

Chapter 1 of this report presents an overview of the approach taken by the Table and highlights some of the challenges in doing the analysis. Chapter 2 deals with the land-use, land-use change and forestry issues as currently addressed in the Kyoto Protocol, and the prospects for negotiations. Chapters 3 and 4 summarize the analyses of forestry options and agricultural soils strategies, and provide insights into other countries' soils potential. Measurement, monitoring and science issues are presented in Chapter 5. Wetland conservation is addressed in Chapter 6 while Chapter 7 portrays the linkages between sinks and the Kyoto Mechanisms and other potential trading systems. Conclusions are drawn in Chapter 8. A compiled list of recommendations is presented after the Executive Summary at the beginning of this report.

1.2 Challenges and Analytical Issues

In common with other Issue Tables, the Sinks Table has had a great deal of difficulty in undertaking many of the studies aimed at improving the knowledge base related to this issue. Lack of competent and/or available expertise and time have been the main constraints faced by the Table. This did not come as a surprise, given the nature of the issue. The requirements of the Protocol require new and original research which, by necessity, must continue after the life of the Table.

Another concern of the Table is that the reliance on potentially unsubstantiated hypotheses, in the absence of quality data, is likely to seriously compromise the validity of estimates. These may be inadequately used in devising a national implementation strategy. Finally, and of no less importance, is the fact that many of the issues surrounding sinks are the direct result of the uncertainties and skepticism in which sinks are held.

Given the respective mandates of the Agriculture and Forest Sector Tables, in the sense that both are including sequestration as part of the contribution of their respective sector towards the Kyoto target, it was logical that any options that were to be developed would have to be done in concert with these relevant sector Tables. With respect to the agriculture options, given the different schedules for completion and delivery of the Options Papers for both Tables, and the intention of the Agriculture Table to undertake some analytical work regarding carbon sinks, the options related to agriculture have not been fully developed to meet the deadline for the Sinks Table's Options Paper. However, these delays may not be that critical given that a number of options for sinks will depend on the result of the international negotiations, which are unlikely to see any agreement until late in the year 2000, at the earliest.

As indicated to the Analysis and Modeling Group on several occasions, costs and emissions and removals associated with the land-use, land-use change and forestry activities cannot be rolled up easily with the emission reduction activities associated with other sectors. Currently, there is no "sinks model" for the three forestry activities included under the Protocol. Among the key issues related to the development of cost curves for sinks are those related to the longer lifetimes of the project, that is the trees, and the huge up-front costs in planting them. There is concern that in a simple comparison of costs with other measures, over the life of a project, these costs may be underestimated. The same issue applies to agricultural soil sequestration. As described further in Chapter 3, a simple cost-effectiveness calculation was done with respect to the afforestation options, both over the assumed lifetime of the project (plantation) (i.e. 2000-2050) as per the AMG guidelines, but also over the first commitment period 2008-2012. It is still unclear whether this information for sinks would be of any use in prioritizing measures and options in a national roll-up exercise.

1.3 Linkages to Other National Tables

Given the horizontal nature of the land-use change and forestry sector, the Sinks Table has had the opportunity to collaborate with a number of Tables, but most specifically with the Forest Sector Table, which has proven of invaluable help. The two Tables held a joint meeting in Vancouver in October, 1998, at which a joint reforestation, afforestation and deforestation (RAD) Working Group was established. The Group has been meeting regularly and fruitfully under the chairmanship of the Canadian Forest Service (CFS) to review the joint studies on RAD and to initiate the process of developing, writing, and reviewing the relevant sections of the Options Report, common to both Tables. The two Tables have also commissioned a joint study on C sequestration issues related to the Kyoto Mechanisms and potential crediting and trading systems.

Over the course of Spring 1999, a similar Working Group of members from both the Sinks Table and the Agriculture and Agri-Food Table was formed and began working on developing strategies for the enhancement of the agricultural soils sinks and on refining soil sink potential estimates for croplands. The Sinks Table has also developed various linkages, including through cross-membership with other Tables, such as the Enhanced Voluntary Action Table, the Municipalities, and the Public Education and Outreach Tables. Dialogue was also maintained with the Kyoto Mechanisms and the Credit for Early Action Tables. The linkages between C sequestration issues and the Kyoto Mechanisms (Clean Development Mechanism, Joint Implementation and International Emissions Trading), Credit for Early Action, as well as emissions trading are dealt with in Chapter 7.

2. LAND-USE, LAND-USE CHANGE AND FORESTRY AND THE KYOTO PROTOCOL

2.1 Background

The Framework Convention on Climate Change (FCCC), adopted in 1992, states that "Each Party shall... limit its anthropogenic emissions of greenhouse gases and protect and enhance its greenhouse gas sinks and reservoirs." While there are different interpretations of this statement's meaning, it is clear that sinks are to be included under the Convention. The Framework Convention defines a sink as "any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere." Currently, photosynthesis, a natural biological process, is the only process considered to act as a sink by removing carbon dioxide from the atmosphere. Hence, carbon dioxide storage in oil and gas wells is not considered a sink under the Convention.

Vegetation withdraws carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis. Carbon dioxide is returned to the atmosphere by the respiration of the vegetation and the decay of organic matter in soils and litter. The gross fluxes are large: gross primary production (gross photosynthesis) is about 120 billion tons per year, of which about half is returned to the atmosphere via plant respiration. The remaining is stored as plant material. Humans interact with land in many different ways. Certain land-uses and land-use changes can directly alter the size and rate of natural exchanges of greenhouse gases (GHGs) among terrestrial ecosystems, the atmosphere and the ocean. The fact that changes in land-use today affect both present and future CO_2 fluxes associated with that specific land-use, is one characteristic that distinguishes land-use from fossil fuel consumption or other sources of emissions for purposes of CO_2 emissions analysis. Ecosystems are in a state of dynamic equilibrium. The size of carbon fluxes and amount of C stored in reservoirs change with time. Each ecosystem has its own profile, depending on its state of succession, climatic factors and exposure to natural and human disturbances.

Tree growth and soil formation take many years to complete (i.e. decades to centuries) making their annual rates of change very small and the realization of their benefits very long. Due to the dominating influence of natural forests in certain countries, such as Canada, the sinks issue is of particular relevance to our country. Young fast-growing trees store relatively small amounts of carbon — they are small carbon reservoirs or pools — but have a rapidly increasing annual carbon absorption rate (they are rapidly growing sinks). At least two or three decades of growth, and sometimes much longer depending on the tree species, are usually required to reach maximum annual sink capacity. The older the forest the greater the amount of carbon it stores. However, as a forest ages it becomes more susceptible to insects and disease and may face a greater likelihood of wildfire. Fire and decomposition of dead organic matter emit carbon back to the atmosphere. A large part of the carbon ends up in the soil, which can be a significant reservoir.

2.2 International Negotiations and Strategic Considerations

The arguments for including sinks in the Kyoto Protocol stem from the fact that the FCCC includes them, and that the best incentive to protect and enhance them is to have them part of a legally binding agreement. In reality, as is shown below, the Kyoto agreement does not quite fulfil that goal. Excluding forestry would have failed to foster the sustainability of forests and would have contradicted the aims of the Convention and other international environmental agreements. On the other hand, the arguments for excluding sinks were that they constitute a loophole, and that because of the large uncertainties, they are unverifiable. However, uncertainties could and should be dealt with as they would be with sources. The onus would be on the reporting Party to ensure that what is reported would meet agreed criteria for verification and compliance. Further complicating matters was the difficult issue of defining anthropogenic removals and emissions from forests, while at the same time creating incentives for countries to conserve and enhance their sinks and reservoirs.

The Kyoto compromise was an agreement to include some land-use change and forestry activities, undertaken after 1990 that affect sinks, namely RAD. These would be added to or subtracted from Parties gross emissions when assessing compliance over 2008-2012, and would be measured as a verifiable change in carbon stocks (Article 3.3). The approach taken was therefore the so-called gross/net approach. This means that if there is an increase in carbon stock between 2008 and 2012 as a result of RAD activities undertaken since 1990, then the average amount of carbon removal during the commitment period will be subtracted from Canada's average emissions in the 2008-2012 period. If

the carbon stock declines (i.e. net carbon emission) as a result of these three post-1990 activities between 2008 and 2012, then the amount will be added to Canada's emissions in the period.

The current focus of the Kyoto Protocol is not the whole Canadian forest, or even some major component of it like the "managed" forest. Instead, the Protocol focuses only on the Kyoto Forest. The changes in carbon stock on the existing forest not affected by those activities post-1990 cannot contribute to Canada's efforts to meet its commitments as currently written in the Kyoto Protocol. By limiting activities, by including activities that do not have a sink term (deforestation), and by specifying how the changes would be measured, the Protocol is not quite balanced in its treatment of sources and sinks. It does not credit and thereby provide incentives for good forest management practices that ensure the sustainability of existing forests. For many countries, the Kyoto Forest represents a small fraction of their existing managed forests. As a result, the Kyoto Protocol is unlikely to provide all of the appropriate incentives to meet the goal of the UNFCCC - "to protect and enhance sinks." Figure 2.1 illustrates in a schematic way the forest-related activities included in the Protocol.

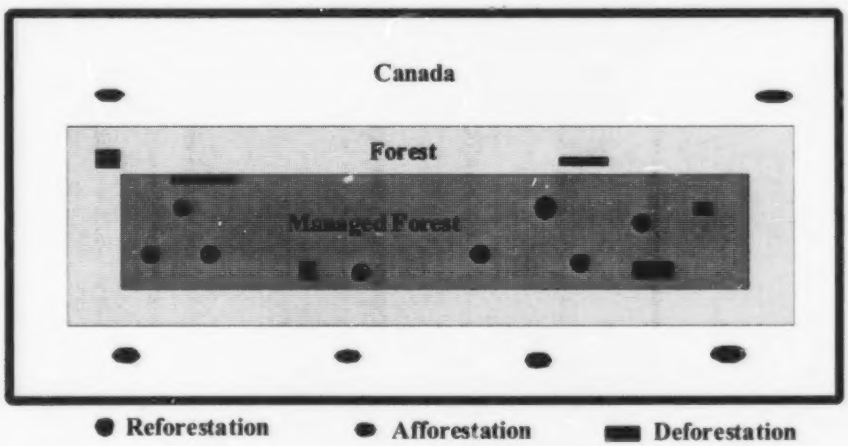

Figure 2.1: **Illustration of Forest-Related Activities Included in the Kyoto Protocol**
(Source: Canadian Forestry Service)

Harvesting was removed from the list of forestry activities that had been originally proposed for inclusion in the Protocol. The reason for this was that countries like Canada, whose forests have a relatively low growth rate, would have been penalized because of the debit taken from harvesting (all the CO_2 from logging is considered to be released to the atmosphere within a year). This would have more than offset any carbon from re-growth on harvested lands since 1990.

Australia supported the inclusion of sinks in a net/net approach only, and was able to negotiate special text to allow this. According to Article 3.7, countries for whom land-use change and forestry constituted a net source of emissions in 1990 will include the net emissions from land-use change only in their 1990 base year and, hence, inflate the GHG budget (or assigned amount) they can emit during the commitment period. However, inconsistencies in the language in Article 3.7 raise the question of whether net emissions from land-use change *and forestry* or just land-use change are to be included in the estimate of base-year or base-period emissions. This could significantly affect the calculation of Assigned Amounts by Annex I Parties, which would impact early-action crediting and domestic and international emissions trading.

National inventories prepared using the current *Intergovernmental Panel on Climate Change (IPCC) Guidelines* do not reflect the boundaries of the Kyoto Forest, nor are most national inventory data collection systems designed to collect data that are specific to the Kyoto Forest. New inventory methods will need to be developed to account for net emissions or sinks from the Kyoto Forest, and Annex I Parties will need to build the institutional capacity to collect the appropriate data and apply these methods.

A key uncertainty is how the three RAD activities will be defined. Different definitions can result in vastly different sizes of sinks or sources. The Foundation Paper had concluded that depending on the final decision on many outstanding issues, the net contribution of sources and sinks from RAD since 1990 during the first commitment period could be either a substantial source or sink. For example, if regeneration after harvest is excluded from "reforestation", a net C sink from the Kyoto Forest could only be obtained with a massive afforestation program. Uncertainties will likely remain for some time, definitions may not be agreed to before a long time, and when they are, the risk will remain that they be interpreted differently.

Agricultural soil sinks are not currently included in the Kyoto Protocol presumably because of the lack of confidence and uncertainties in the estimates, and the fact that Parties are unsure of the state of their soils and have not reported on them. A related key issue is whether the Kyoto Protocol could or should be interpreted to include carbon losses from agricultural soils as a source in calculating the assigned amount. While most seem to believe soils are in as a source in the base year, others think it could be a tenable position to argue that they are not, given the vagueness of certain provisions in the Protocol, such as Articles 3.1 and 3.7.

In Article 3.4, the Protocol allows for negotiations on what and how additional sinks activities (other than reforestation, afforestation and deforestation), including agricultural soils, can be used to meet commitments. The Conference of the Parties (COP) of the Convention will decide upon modalities, rules and guidelines as to how carbon removals in agricultural soils (and any additional land-use change and forestry activity) shall be taken into account. Thus the key to gaining international acceptance of carbon sequestration in agricultural soils is to have a confident projection of the potential, both nationally and internationally, and an agreed methodology for determining "verifiable changes in stock." Some argue, including Canada, that while these methodological issues are recognized, uncertainties should not be seen as a valid reason to exclude agricultural soils.

The LULUCF negotiating dynamics are very awkward and progress is very slow on all the issues. At times in the last session in June 1999, it appeared that countries were taking a step backward from what was agreed to in Buenos Aires. This was because some Parties have systematically refused to engage in any meaningful discussions, which has resulted in the absence of progress on policy and procedural issues for inclusion of additional activities or on definitional matters related to Article 3.3. Some Parties believe that none of this should be addressed until after the completion of the IPCC Special Report (SR) on Land-Use, Land-Use Change and Forestry, in May 2000. It is important, though, that a parallel process continue since the SR will not address the policy decision-making framework or the criteria. It will simply provide, among other things, valuable insight into the implications of various sets of RAD definitions. Another issue among the negotiating Parties will be the submission of data, its timing, and most importantly, its use in the decision-making process. At the June session, however, it was decided that two workshops will be held. One is to be an in-depth progress report on the draft IPCC SR on the margins of CoP5, along with a side event to allow for interaction, during the government and expert review period of the report. One goal of this event would be to ensure the policy relevance of the SR. Another, more in-depth workshop will be organized between SBSTA 12 and CoP6 to analyze the IPCC SR.

A number of countries, including Canada, are of the view that Parties should agree on the criteria that should guide the inclusion of new activities under Article 3.4. Canada has proposed that the criteria established to address these uncertainties should be based on sound science; promote other environmental objectives related to land-use; maintain symmetry and consistency in the treatment of land-uses; and promote rather than undermine the objectives of the Convention. A consequence of the negotiations for the inclusion of additional activities could be that countries will account for them maybe only in the second commitment period. Two considerations have to be kept in mind when negotiating additional activities. First, the accounting method that will be used for the period 2013-2017 and beyond is unknown and may be different than that of the period 2008-2012. Second, the new emission reduction target for the second period remains to be negotiated, keeping in mind the potential additional activities that may be included.

2.3 Research Collaboration and Information Transfer

It is in Canada's best interest to undertake a major role in developing the international modalities, rules and guidelines for reporting sequestered carbon under the Kyoto Protocol in a transparent and verifiable manner. To do so, Canadian scientists must actively seek international collaboration with, and hence acceptance by, scientists from other countries in developing the data bases, monitoring systems and models needed for such reporting. They should also be active participants in international scientific assessments such as those conducted by the IPCC, which will be critical in developing international consensus on rules and guidelines. Hence, to foster such input and collaboration, some priority should be given for funding of multi-lateral research programs and workshops on carbon process studies and for participation in international assessments.

Recommendation 2.1: relevant government departments should encourage their scientists and technical experts to undertake the research priorities identified in close collaboration with peers within the international community, and to use expertise appropriately in future negotiations related to carbon sinks within the context of the Kyoto Protocol.

3. CARBON SEQUESTRATION OPTIONS IN FORESTRY AND LAND USE CHANGE

3.1 Introduction

This Chapter deals with land-use, land-use change and forestry options related to increasing forestry sinks and reducing forestry sources for those forest-related biological sources and sinks that are or may be included under the Kyoto Protocol. This chapter is quite similar to Chapter 4 of the Forest Sector Table Options Paper given that it is based on the work of the Sinks and Forest Sector Tables' Joint Working Group and it was written jointly. Some differences arise, however.

As noted in Chapter 2, the Kyoto Protocol as currently written does not consider the whole Canadian forest, or even a major component of it like the "managed" forest. Instead, the Protocol includes only three specific activities related to forests - reforestation, afforestation and deforestation (RAD) since 1990. Thus changes in the carbon in Canada's total forest have no bearing on Canada's efforts to meet its Kyoto commitment. Chapter 5 elaborates on the measurement requirements to account for RAD and insists on the fact that these will be completely clear only after further international negotiations.

Because of the uncertainties surrounding the outcome of the negotiations, the domestic carbon sequestration options are presented in three separate sections: activities that are currently in the Protocol and have relatively high certainty of being defined in a way such that options are relevant (i.e. afforestation); activities that are currently in the Protocol but have relatively uncertain definitions (i.e. reforestation and deforestation); and activities that are not currently in the Protocol but that are being considered for inclusion (e.g. all forest management activities on the managed forest). We also include in the latter category a discussion of the storage of carbon in forest products. The current IPCC guidelines (i.e. for reporting on GHG inventories under the UNFCCC) treat harvests as an emission in the year of harvest. However, it is not clear if these guidelines will be applied under the Protocol, and even if they are used (as opposed to the adoption of new ones), they may be modified to better reflect the actual carbon flows when trees are harvested and made into forest products. If carbon stored in forest products is included under the Protocol, then this has implications for potential strategies to enhance carbon stocks.

When a truly long-term perspective is adopted (>100 years), it becomes evident that forest sinks have only a modest role to play in addressing climate change, since there are biophysical and practical limits to how much carbon can be stored in forests and forest products. Forest sinks cannot provide a permanent solution to the problem of anthropogenic climate change, and activities to enhance forest sinks should be considered an interim measure to supplement measures aimed at reducing GHG emissions. While the total store or stock of carbon in forests may be permanently increased, after a time, the net removal of CO_2 will equal zero, so that there is no further sink uptake.

Since carbon sinks and sources are not included in the *Energy Outlook*, which is used as the Business as Usual (BAU) (or more accurately "policy as usual") emissions baseline, we provide an estimate of the BAU for sinks and sources under the Kyoto Protocol. Because of the definitional uncertainties noted earlier, there is, in fact, a set of BAU scenarios that correspond to the different potential negotiation outcomes related to both definitions and activities included under the Protocol. In terms of the Protocol, the BAU estimates are what would be available to be offset against Canada's emissions target in the first (or subsequent) commitment period(s), without additional investment or changes in policy.

The discussion in this Chapter focuses largely on either increasing the amount of carbon that is stored on a given area and/or increasing the area that is forested relative to the BAU (this includes reducing the area deforested). Sequestration options require a set of policies or programs to be put in place to increase the net carbon sequestered in the first and subsequent commitment periods.

3.2 Currently in Protocol with High Certainty of Definition – Afforestation

The term 'afforestation' has not yet been defined for the purposes of the Kyoto Protocol, and international agreement on a definition is not likely for several years. However, it should be noted that under virtually all sets of definitions being discussed, planting of trees on marginal agricultural land as described here would be included under the Protocol — although it might be defined as reforestation rather than afforestation. There are two basic possible definitions for afforestation. The IPCC definition reads "planting of new forests on lands which, historically, have not contained forests." Canada, in a submission to the IPCC for the IPCC special report, had suggested the following working definition: "a change in land-use that, through the establishment of a stand of trees, forms a forest."

Closely related to the IPCC definition of afforestation is its definition of reforestation: 'planting of forests on lands which have, historically, previously contained forests but which have been converted to some other use.' Under the IPCC definitions, the actions described below would be considered a mixture of afforestation and reforestation although ascribing specific areas of newly planted forest to one or the other could be difficult in instances where the historical land cover and land-use changes are not known with certainty. Canada's suggested working definitions are used in this Options Report but it must be kept in mind that these may not be accepted. Implications of the uncertain negotiating outcomes are described further below.

The BAU estimates of afforestation presented in the Sinks and Forest Sector Table Foundations Paper indicated a potential of 1-2 Mt CO_2/year in the first commitment period, based on very rough estimates of current rates of tree-planting and changes in land-use (assumed to equal about 15,000 ha per year). Further consideration of these estimates has led to the conclusion that most of these areas would not be considered afforestation under the Kyoto Protocol (as noted below, tree planting might not be considered afforestation), or would be difficult to monitor and verify. Part of this background afforestation are abandoned farmlands re-growing naturally to forests, and the data and methodology used to estimate it are highly uncertain. Tree planting corresponds to approximately another 12,500 ha/yr (Lemprière and Booth, 1998). The BAU estimates for afforestation, assumed to be negligible for this exercise, should be refined.

The Forest Sector and Sinks Tables assessed a variety of afforestation actions based on tree species used, type of afforestation and region, as shown in Table 3.2.1. Background information for the assessment of these actions was provided by five studies commissioned for the Table on afforestation potential in Canada, and a sixth study on design and implementation options for afforestation programs (see Annex B). It should be noted, however, that the results discussed here are not directly comparable to those in the studies, as further internal analysis was done that required various changes in assumptions and modifications to the analysis. The results shown in Table 3.2.1 are subject to many uncertainties and are of low to medium confidence. The carbon sequestration, costs and cost effectiveness are very sensitive to the assumptions used, of which the most important are tree growth curves, areas afforested, planting schedules, the value of the activities given up when the land is afforested, discount rates used for financial flows (10%) and carbon flows (no discounting). Tree growth in the early years after planting and growth rates on plantations are areas of great uncertainty, and there is a need to compile and synthesize data for various species from provincial and other databases across Canada.

The calculated net cost of afforestation should include planting costs, the opportunity cost of the land, protection costs and the transaction costs associated with afforestation programs and measuring, monitoring and verifying carbon sequestration. It should also include the value of various possible uses, including forest products and bioenergy, (and the value of the carbon) and a wide variety of environmental benefits and uses such as soil protection, water quality improvements and habitat enhancement. Information on the values of most of these benefits is uncertain, in large part because of uncertainty about the future value of carbon, uncertainties about market opportunities for use of the wood for forest products (and how harvesting and forest products carbon will be dealt with in the Protocol) and the difficulty of quantifying the environmental benefits and uses. Our analysis is based only on assessment of planting and opportunity costs — thus the cost-effectiveness results are not based on the true net cost of afforestation since not all costs and benefits are included.

Overall, the results indicate that a concerted effort to afforest 50,000 ha in fast-growing species over five years (2001-2005) will result in 1.3 Mt CO_2 in 2010. Planting 793,000 ha over 15 years (2001-2015) in slower-growing species results in sequestration of 0.8 Mt CO_2 in 2010 though this estimate is of low confidence, reflecting considerable uncertainty in tree growth in the first few decades after planting. While we assumed that planting could start as early as 2001 at a modest level (12,200 ha of traditional species and 10,000 ha of fast-growing species) and build over time (61,000 ha per year of traditional species in 2006-2015), this is a very optimistic assumption and will require an immediate and intensive effort to achieve. Delaying start-up to 2002 or 2003 significantly reduces carbon sequestration in the first commitment period but may be necessary. Differences in cost effectiveness and sequestration across actions reflect regional differences in species planted, growth curves, planted areas and planting costs.

The planting levels of the actions exceed by far any previous afforestation effort in Canada. Planting on recently harvested lands exceeds 400,000 ha per year in Canada, almost all of it on publicly owned forest land, so that a great deal of planting expertise and knowledge can be called upon for afforestation. However, as discussed below, the real challenge with an afforestation effort of the level proposed in the actions is the complexity and difficulty of attracting thousands of individual landowners of marginal agricultural and other land.

Note that to achieve the total sequestration of 2.1 Mt in 2010, the full planting effort need not be undertaken (i.e. planting need only occur in 2001-2009) but planting the annual target over the full 15-year period results in a substantial increase in sequestration in the years subsequent to the first commitment period. Also note that annual carbon sequestration after 20 or 50 years due to planting traditional species will be substantially higher than it is in 2010. Whereas it is 0.8 Mt CO_2 in 2010, by 2020 it is around 2.9 Mt CO_2, and in 2050 it is about 7.5 Mt CO_2. Over the 2000-2050 period, carbon sequestration averages over 4 Mt CO_2 per year from planting traditional species.

Of particular note in Table 3.2.1 is the difference in the carbon sequestration and cost of planting fast-growing tree species compared to planting larger areas in slower growing species. Compared to the latter, fast-growing plantations are much more cost effective and result in significantly more sequestration in the first commitment period. Over a longer time period, fast-growing plantations are less favourable because the trees have much shorter lives. Planting fast-growing species might often be done with the goal of harvesting the trees in 12 to 15 years and this raises complicated, and as yet, unresolved issues about how harvesting of afforested areas will be treated in the Protocol.

Table 3.2.1
Summary of Afforestation Actions[1]

Action	Annual Planting Target[2] ha/yr	Planting Period	Total Planting ha	Cost Effectiveness[3] 1997$/t CO_2e		Carbon Sequestration[4] Mt CO_2e	
				2008-2012	2000-2050	2010	2000-2050
Fast-growing plantations	10,000	5 years	50,000	22.2	na[5]	1.31	na[5]
Prairie shelterbelts	13,000	15 years	169,000	140.7	3.7	0.15	29.0
B.C. block plantations	13,000	15 years	169,000	452.5	2.4	0.04	35.2
Prairie block plantations	20,000	15 years	260,000	114.6	3.0	0.37	71.4
Eastern block plantations	15,000	15 years	195,000	144.9	2.3	0.22	68.6
TOTAL			**843,000**			**2.08**	

1 The sequestration and cost-effectiveness estimates for the first commitment period are considered to be of low confidence. Other estimates are considered to be of medium confidence.

2 All planting starts in 2001. With the exception of the fast-growing species action, all planting ramps up to the annual planting target by 2005. For the fast-growing species action, full annual planting starts in 2001.

3 The costs include planting and maintenance costs only. Not included are the cost of protection and the transaction costs associated with afforestation programs and carbon measuring, monitoring and verification systems. Also not included are revenues from the harvest and use of the tree, and the value of environmental benefits.

4 Only above- and below-ground tree biomass carbon is included in the net sequestration estimates for the fast-growing plantation action and the Prairie and B.C. actions. The Eastern Canada actions also include soil and non-tree biomass carbon. Emissions from the use of fossil fuels in planting are accounted for in the estimates.

5 For the fast-growing species action, the assumption is that harvesting, if it occurs, will happen at age 13 to 15 years and the area is replanted. Over the 2000-2050 period, the net carbon sequestration will then depend on how harvesting of afforested areas and carbon in the resulting forest products are treated in the Protocol.

The details of the analysis for each action are described below in Sections 3.2.3 to 3.2.7. Before presenting the details for each action, it is important to review the analytical issues and uncertainties in the analysis, and the assumptions that were used. This is the subject of Section 3.2.1. Section 3.2.2 describes impediments to the afforestation actions and policy considerations. The review of the afforestation actions closes in Section 3.2.8 with a brief assessment of other issues, including competitiveness, economic and environmental implications of afforestation, the use of planting programs in other countries with Kyoto emission reduction or limitation targets, and further analytical needs to improve our understanding of afforestation actions.

It should be noted that the analysis here presents the perspective of the Forest Sector and Sinks Tables. However, much of the focus of the actions is on agricultural land and these actions need to be assessed further from the perspective of the agricultural sector. A detailed comparison of these actions to the carbon sequestration potential of shrubs and non-woody crops on agricultural land, as well as practices to increase agricultural soil carbon, would be useful.

3.2.1 Analytical Issues, Uncertainties and Assumptions

Types of Afforestation and the Use of Afforested Areas

For the purposes of the analysis, the Forest Sector and Sinks Tables distinguished three types of afforestation based on their different effects on existing land uses and the types of land that typically may be involved with each (see Table 3.2.2). The discussion here focusses only on the first two — block plantations and shelterbelts. A block plantation is a relatively large area devoted to trees, while shelterbelts involve rows of trees such as those planted around farm field perimeters. It should be noted that shelterbelts would likely not be included under a "land use-change" type definition of afforestation, although this is subject to debate.

There are significant differences between block plantations and shelterbelts in terms of their potential future uses (other than for carbon sequestration) and potential future carbon debits, the economics of afforestation, species selection and policy considerations. These issues are discussed below.

Table 3.2.2
Types of Afforestation and Potential Uses

	Block Plantation (relatively large block of trees)	**Shelterbelt (rows of trees)**	**Tree Planting (small-scale, scattered tree planting)**
Target land type	Probably marginal agricultural land, but may target unused or under-utilized good quality agricultural land where productivity is highest	Agricultural land where soil erosion exists or other benefits may be derived	Any land type
Magnitude of effect on current land use	For individual landowners, requires a large-scale conversion of land use	For individual land-owners, land-use conversion would be minimal or moderate	Little or no effect on current land use
Purpose/Use	Carbon Fibre for products or bioenergy Environmental uses - restoration of degraded and fragmented forests, biodiversity, habitat enhancement, aesthetics, improved water quality and quantity, soil conservation and protection	Carbon Improve crop yields, reduce energy use in buildings Environmental uses - aesthetics, improved water quality and quantity, soil conservation and protection, protection from wind and sun, aesthetics, improve water quality and quantity, noise reduction	Carbon Reduce energy use in buildings Environmental uses - aesthetics, improved water quality and quantity, soil conservation and protection, protection from wind and sun, aesthetics, improve water quality and quantity, noise reduction

A key uncertainty in the analysis of afforestation is the future use of the afforested areas. Choices about the purpose(s) of afforestation in any given area will help to determine who will be interested in afforestation, their degree of participation, the level and structure of incentives required to encourage involvement and the time path of future carbon credits and debits that they (and Canada) will be responsible for. It will also influence the choice of species used and the environmental, social and economic effects of the afforestation. All of these issues are discussed further in this section and in the following section. Here, the variety of possible uses are described.

Clearly, carbon sequestration and the creation of carbon reservoirs is a primary goal in the context of the Kyoto Protocol and the Framework Convention on Climate Change. Broadly speaking, there are two other classes of use, one related to harvesting for forest products or bioenergy and the other related to environmental or other goals which generally do not involve harvesting. In many cases, there could be multiple end uses. In general, an intent to achieve goals beyond just carbon sequestration will likely be the most successful approach to the development of afforestation programs. Such goals would vary from location to location.

In the context of the Protocol, harvesting and the assignment of the associated carbon credits and debits is a difficult issue and one that is still unresolved at the international level. This is discussed further below. There are important differences between block plantations and shelterbelts in this regard. Block plantations are more likely to be harvested at some point in the future, while the removal of shelterbelts generally is not anticipated. If the afforested area remains permanently in forest then eventually the net annual carbon sequestration will fall to zero as the carbon stock stabilizes (i.e. net emissions through decay will equal growth). For the slowest growing species this could take over 100 years.

In addition to the possible economic benefits of harvesting, there are a wide variety of environmental non-market benefits that can result from afforestation on areas that may or may not be harvested in the future. These include restoration of degraded or fragmented forests, wildlife habitat enhancement, biodiversity protection and enhancement, improved water quality and quantity, and soil conservation and protection. Other potential benefits, especially for shelterbelts, are noise reduction, protection of buildings from the wind, sun and cold (which can reduce energy consumption for space heating and cooling), aesthetic improvements and improvements in crop yields.

Uncertain Negotiating Outcomes

International agreement may not be reached until CoP6 (Fall 2000 or beginning of 2001) or later on the definitions of afforestation and reforestation, and on which carbon stock components will be counted for the purposes of determining compliance with the Protocol. It seems clear that block plantations will be included in the Protocol irrespective of the definitions of afforestation and reforestation which emerge from future negotiations. It also seems likely, though less certain, that shelterbelts may be included. The IPCC definitions and the Canadian proposed working definition both mean that tree planting as defined in Table 3.2.2 probably would not be included in the Protocol unless the planting qualifies as establishing a forest.

In terms of carbon stocks, it is clear that carbon sequestration from above-ground tree biomass is included, but there is some uncertainty as to whether carbon sequestration in soils and below-ground biomass will be included. In the analysis by the Forest Sector and Sinks Tables below-ground tree biomass carbon was estimated and soil carbon was included where it could be estimated. Another issue related to carbon stocks is whether carbon sequestration on a given area of land, in the absence of afforestation, must be accounted for. Prior to afforestation, the land may be either a sink or a source because of the vegetation already on the land and how it changes over time,. It is possible that this existing sink (source) would have to be subtracted (added) to the carbon sequestration resulting from afforestation so that only the net increase in carbon due to afforestation is accounted for in assessing credits. The action analysis does not take this into account.

Future negotiations also will determine whether activities which enhance agricultural soil carbon sequestration will be included. This is of relevance for the analysis of afforestation, as the inclusion of agricultural soils creates the potential for competing actions and policies to promote carbon sequestration on the same agricultural land either from afforestation or from agricultural soil sequestration.

A fourth key uncertainty is how harvesting of areas afforested since 1990 will be treated in the Protocol. At issue is whether harvesting will result in debits, and if so, how the carbon stored in forest products is counted and who owns the credits when the products are traded.

A final major uncertainty is related to the guidelines, rules and procedures for measurement, monitoring and verification of carbon sequestration that will be determined by future international negotiations. The costs of these activities will

vary according to the requirements, the type of afforestation and afforestation policies. These costs were not assessed by the Forest Sector and Sinks Tables.

Land Availability and Participation Rates

The biophysical suitability of land is not a limiting factor for afforestation in Canada. Instead, the potential for afforestation is a function of financial and other factors. Thus the portion of the suitable land that will actually be made available for block plantations and shelterbelts is very difficult to estimate, as it depends on a range of factors including current land uses and their financial returns, ownership, owner characteristics and motivations, and location. It also depends on factors related to the afforestation program implementation such as awareness, promotion and credibility.

In some parts of the country there are areas of publicly owned marginal agricultural land which could be used for afforestation. In general, however, relatively little agricultural land is publicly owned and the afforestation actions presented in this Options Report are aimed primarily at privately owned land, especially marginal agricultural land (the policies to implement afforestation on public land would be much different than those discussed here). To access private land, plantations and shelterbelts will require participation of thousands of heterogeneous private landowners. This means that the impact of afforestation programs will ultimately be determined through a bottom-up process in which thousands of individual owners of farms and other land make the decision on where, when and if they wish to participate. It is the participation rate (number of landowners, area per landowner) that will determine the total land made available. It also will determine when the land will be made available, which affects the planting schedule, and therefore, affects how quickly carbon is sequestered.

In the analysis of all but one of the afforestation actions (the fast-growing plantation action is the exception), we assumed the following relatively quick ramp-up in the planting schedule will occur:

2000	program start-up
2001	20% of annual planting target
2002	40% of annual planting target
2003	60% of annual planting target
2004	80% of annual planting target
2005	100% of annual planting target
subsequent years to 2015	100% of annual planting target.

Even with significant incentives to landowners and widespread publicity, involvement in afforestation is likely to proceed slowly at first, as programs and policies are implemented, financing mechanisms are developed, landowners and others learn about opportunities, technical advice is developed and made available, rules for carbon accounting are developed and nursery stock is made available. To take these factors into account, we have assumed that planting will start in 2001 at a modest level. Some Table members, as well as external reviewers, stressed that start-up in 2001 was a very optimistic assumption. For example, a 2001 starting date for planting would typically require a two-year lead time for provision of seedlings (i.e. in 1999). This is not likely to happen, and suggests that planting might not start until 2002/2003 at the earliest in some regions, given the time that would be needed to first obtain participation of landowners.

Determining likely rates of participation in afforestation is no easy matter and requires an assessment of the up-front costs and benefits to landowners, future costs and benefits, and their personal preferences and goals related to current and future land use. In trying to determine participation rates, and the land that will be made available, there are two key questions: 1) what incentives do landowners need to participate? and 2) how will the incentives be provided? The incentives that landowners will require may not be only financial, but also could include technical assistance and information on the impact of afforestation on the land.

There will also be landowners who simply will not be interested in afforestation. Some farmers, for example, may not be interested because their family has been farming for many generations, or because they do not wish to be locked into long-term use of their land for forests. Such non-biophysical and non-financial constraints could be considerable.

The land that each landowner will make available will be a function of average land holding and individual owner decisions about what portion of their land they will afforest. Afforestation based on a lot of small plots owned by many people is likely to be more expensive than larger plots involving fewer landowners, though incentives for afforestation could be structured to encourage large, contiguous blocks of land. This could be done by providing incentives for groups of landowners to organize cooperatives.

Afforestation Costs

We started our afforestation analysis by deciding on actions for afforesting areas of land considered ambitious but realistic. Given a target level of afforestation in terms of area, and the characteristics of the land and landowners likely to be involved, there will be a certain level of cost that will be required. How these costs are financed (e.g. with government funding, revenue from carbon credits, funding from companies interested in using wood, etc.), how participants in afforestation other than landowners can be involved, the types of incentive mechanisms that might be used, and other issues related to afforestation program design are discussed in the following section on policy considerations.

While financial concerns are not the only considerations of landowners, in order to secure their participation many will have to be compensated for the costs of planting and maintaining block plantations and shelterbelts. From the perspective of the landowner, there are three costs (the benefits and potential revenues are discussed in the next section).

1. Landowners sometimes earn revenues from their land which will be lost when afforestation occurs (i.e. there is an opportunity cost of afforesting the land). This is especially true of farmers who may have crops on the land or use it for grazing, though the primary focus of afforestation is more likely to be on lands that are not currently being used for agricultural purposes and so earn little revenue. Compensation for opportunity costs, whether paid by governments or by others interested in afforestation, could be in the form of a one-time payment, or through an annual land rental payment. While the present value of these two forms of payments might be equal, they may have different effects on landowners and one may be preferred over the other depending on the targeted landowners. From the perspective of a need to maintain carbon stocks, one concern about annual payments is that the landowner may come to rely on them, and once they are stopped he or she may choose to cut the trees and not replant (i.e. deforestation), which would result in a carbon debit. On the other hand, annual payments may be attractive because they could convince landowners to treat trees as a crop. In contrast, one-time, up-front payments may attract landowners with a longer-term interest in maintaining the forest. Whatever the form of the payment, a commitment to maintaining the land in permanent forest is crucial.

   Payments for conservation easements are one way to ensure a permanent commitment. Such easements could require that the land remain forested, or it could require the use of sustainable forest management practices in accordance with provincially established silvicultural guidelines. The easement would be permanent and would not change with change in ownership of the land, an important consideration in some parts of the country where land ownership changes are fairly frequent (10 to 20 years). Easements may be opposed at a local government level because they may reduce the economic activity and property taxes associated with the land.

2. The establishment and maintenance of forests entails costs related to site preparation, acquisition of seedlings, planting, fertilization if necessary, and follow-up activities such as weeding.

3. Finally, afforested areas face the risk of being fully or partially destroyed by fire, pests and windthrow. Fire and pest protection could have quite a significant cost. At present, it is difficult if not impossible to obtain insurance for these risks but if large scale afforestation efforts occur then risk insurance may become more readily available. The risk of catastrophic losses to plantations in the short run is likely to be ameliorated by the fact that the forests will be easily accessible, relatively small and relatively young.

In the actions analysis we show estimates based only on opportunity and planting costs. We did not quantify the cost of forest protection. Establishment and maintenance costs are relatively easy to quantify based on widespread experience with reforestation costs in Canada. They typically range from $1,000 per hectare to $1,500 per hectare but they can be much higher in some cases (e.g. $3,600 per hectare for planting fast growing hybrid poplar). These costs are spread out over several years and the present value is calculated using a 10% discount rate.

Opportunity costs are much more difficult to quantify and there was some divergence of opinion among Table members as to the appropriate values to use. Opportunity costs will vary significantly from location to location, according to the use and productivity of the land, and they may also vary depending on the magnitude of agricultural support programs offered. There is little information on the value of the uses, if any, of the land that most likely would be offered for afforestation. Some guidance can be taken from considering average per hectare farm profits, appraised land values and average farmland values. These sources suggest that annual rental values for farmland are on the order of $100-300 per hectare per year across the country. There are reasons to think that the annual opportunity cost for planting forests would be much lower than this. First, much of the focus of the plantation actions discussed here is on marginal agricultural land and much of this land likely is not being used currently for agricultural purposes. Second, non-agricultural landowners usually will not earn any direct revenue from their land. Finally, there are many farms which have an annual land rental value well below the average, and they may be most likely to participate in afforestation.

These reasons imply that, while the average opportunity cost is not likely to be zero, it could be relatively low. There are also likely to be important regional variations. Some Table members suggested that a significant amount of land might be made available at an opportunity cost of zero or close to zero in Eastern Canada. This reflects the relatively high proportion of land that could come from owners who already have woodlots on their land and who are familiar with forests. In contrast, in the Prairies most of the land is likely to come from owners with more purely agricultural experience and land uses so that opportunity costs could be higher than in Eastern Canada.

In the absence of any definitive information, we made the ad hoc assumption that the annual opportunity cost of the afforested land is $10 per hectare per year. This is roughly equivalent to a land value of $100-125 per hectare. For Western Canada, we did sensitivity analysis to assess the effect of using an opportunity cost of $100 per hectare per year. For Eastern Canada we assess the sensitivity of the estimated cost effectiveness to an opportunity cost of $50 per hectare per year. Since fast-growing species may be planted on higher-quality land, we assumed a somewhat higher annual opportunity cost of $25 per hectare year. This is at the low end of the range of annual land rental payments that have been made for hybrid poplar plantations in eastern Ontario ($25-30/ha/yr) and southern B.C. ($100-300/ha/yr). The present values of the $10/ha and $25/ha annual opportunity costs are calculated using a 10% discount rate over a 25-year period.

A fourth cost of afforestation is the transaction cost associated with developing and administering afforestation programs, and assessing the associated carbon credits and debits. **We have not attempted to estimate these transaction costs, though they could be substantial.** In total, the afforestation actions analyzed by the Forest Sector and Sinks Tables involve about 800,000 hectares over 15 years. By comparison, average farm sizes across Canada range from about 75 to 125 ha in Eastern Canada and British Columbia (B.C.), and 300 to 450 ha in the Prairie provinces. If individual landowners who participate provide 10-100 ha each, the afforestation actions would require involvement of roughly 8,000 to 80,000 landowners across the country. Recruitment and support of this many landowners will involve a sustained, well-resourced effort that is beyond the current capacity of any existing government agency. However, the involvement of partners such a wood-lot owner associations and other non-governmental organizations to help deliver regional programs could be an effective approach.

The cost of measuring, monitoring and verifying carbon sequestration and possible emissions could be large. While most of these costs might be borne by governments, it is possible that some of the costs would be borne by landowners or others involved in afforestation.

Choice of Species and Tree Growth Curves

Given the land made available for tree planting, a further key determinant of sequestration is the choice of species. Species traditionally used for forestry, and for which seedling stock is relatively abundant, have relatively low sequestration rates in the Canadian climate, though their growth in plantations is very uncertain. Anecdotal evidence suggests that spruce and pine in plantations in Canada could reach peak annual growth in 25 to 50 years — much faster than the 40 to 75 years typical of unmanaged stands of these species. Faster growing species such as hybrid poplar can reach peak annual carbon sequestration rates in 10 to 25 years. The fastest growing tree and shrub species can take as little as 5 to 10 years.

Since a primary goal of afforestation will be carbon sequestration, choosing species which maximize sequestration will be an important criteria, though different species would be chosen depending on whether the goal is maximum carbon in a short time period or maximum carbon over a longer period, in addition to other important goals. For the former goal, fast-growing species would be chosen. For the second, slower growing traditional species would be used. Where other purposes for the trees are also important, then specific species for these purposes would be chosen. For example, use in forest products or for bioenergy would likely involve only one or a few species, while a goal of forest restoration or habitat enhancement would require a more diverse set of locally prevalent species. With a mix of uses, a balanced species selection will be needed. Choice of species should also reflect other concerns (e.g. those related to biodiversity, on which Canada has made international commitments). In the afforestation action analysis, we show a fast-growing species plantation action as well as regional plantation actions which use traditional species.

We did not assess the impact of using shrub species in afforestation efforts. Such species could be a cost-effective approach and further analysis needs to be done in this area. Shrub species currently represent a major focus of the Prairie Farm Rehabilitation Administration Shelterbelt Centre. However, it is unlikely that these would be considered afforestation under the Protocol.

Whatever the species chosen, a serious difficulty in estimating sequestration is the lack of good information on growth curves for trees in plantations. The difficulty is compounded by the lack of good data on plantation growth in the first two decades after planting, the key period for determining the impact in the first commitment period. These difficulties mean that we consider the sequestration estimates for the first commitment period to be of low confidence. However, because our knowledge of tree growth after the first two decades is much better we have medium confidence in our estimates over a longer period such as 2000-2050.

The growth curves used in the analysis are from a variety of sources including provincial governments and previous work on afforestation potential. The use of various sources meant that curves for different regions/species were not always consistent though we attempted to ensure as much consistency as possible. We tried to use growth curves that account for the fact that afforestation often will involve relatively intensive management on relatively good-quality land (even though it may be marginal for agricultural purposes) so that growth will be fairly rapid compared to unmanaged natural forests. Table 3.2.3 summarizes the mean annual incremental growth for several representative species used in the analysis. As can be seen, growth rates in the first decade vary much more than the average annual growth rates over 50 years, though the latter are much more reliable estimates than the former.

Table 3.2.3
Growth Curve Mean Annual Increments of
Representative Tree Species Used in Afforestation Analysis
m^3/ha/year of bolewood

	Mean Annual Increment	
Region/Species	**Age 10**	**Age 50**
B.C. Coast Douglas-fir	0.4	10.9
B.C. Southern Interior lodgepole pine	0.4	4.0
B.C. Interior aspen	0.2	3.0
Prairie white spruce	0.4	3.1
Prairie aspen	1.8	3.0
Eastern white and black spruce	0.9	4.7
Eastern red pine	2.3	5.2
Hybrid poplar - good sites[1]	13.2	0.8

1 Hybrid poplar stands are assumed to start to break up by age 30, so that by age 50 the mean annual increment is very low. In practice, hybrid poplar stands would be harvested after 12 to 15 years. If left, the total site carbon could continue to grow depending on the succession of other species.

Figure 3.1 shows the growth curves used for three species. Several key points should be noted about the curves. The first is that annual growth in the early years is slow for the two traditional species shown (i.e. the curves have a low slope) and that it is not until 15 or 20 years after planting that growth becomes sufficiently fast to allow substantial annual carbon sequestration. Second, annual total growth, and therefore carbon sequestration, can vary widely at a given point in time depending on the species chosen (i.e. the slope of the curves at a given age can differ markedly for different species). Finally, for the purposes of the Kyoto Protocol, carbon credits in the first and subsequent commitment periods will be calculated as the difference in the volume at the end a period and volume at the beginning of the period, irrespective of total volume. In other words, what counts is not the total volume at a given point in time, but the change in the volume over specified periods.

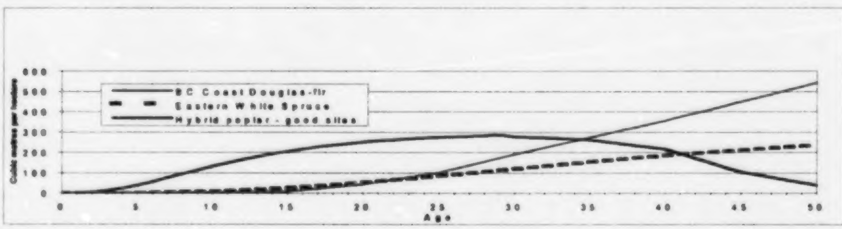

Figure 3.1: Growth Curves for Three Species Used in Afforestation Analysis (bolewood volume per hectare)

Future Harvesting and Deforestation of Afforested Areas

An important uncertainty about afforestation is how carbon will be counted if trees are removed from an afforested area. If the area is harvested and not replaced by a new forest, or is otherwise deforested, then it seems clear that a debit will result for that area, since deforestation is included in the Protocol. At a national level, if an equal area is planted then it will sequester an amount of carbon over time that is roughly equivalent (depending on species chosen) to the deforestation debit. Thus, over time there would be no net effect though the time path of the credits (which occur over a long time) and debits (which occur over a short period) needs to be kept in mind. Note also that achieving no net effect over time means accepting a permanent commitment to maintaining, at a national level, a given total afforested area, though its location in the country could change over time.

Alternatively, if the area is harvested and replaced by a new forest, then the issue is whether or not harvesting of afforested areas results in a carbon debit in terms of the Kyoto Protocol. One view is that, since the activity of harvesting is not explicitly included in the Kyoto Protocol, then there will be no debits. An alternate view is that once the land enters in the Kyoto forest (the area subject to reforestation, afforestation and deforestation since 1990) then any changes in the carbon stock on the land, whatever the cause, are included in the Protocol. This difference of opinion still needs to be resolved internationally.

If the harvesting does count as a debit, then there will need to be international agreement on appropriate accounting for storage of carbon in forest products, including who receives the credit for the stored carbon after the forest products are traded. Storage of carbon in forest products likely would mean that the debit resulting from the harvest would be less than the carbon sequestration that had occurred prior to the harvest. If the harvesting does not count as a debit, then one possibility is that credits from any particular site may cease after the first rotation, since there is no net additional sequestration over and above the maximum volume at the time of harvest.

Irrespective of how harvests or carbon in forest products are treated in the accounting, using the harvest to provide fibre for new processing facilities that would not otherwise be constructed in the BAU world will add to Canada's baseline fossil-fuel emissions. The increase in emissions because of these new facilities would have to be accounted for and would offset some of the afforestation carbon credits.

If the wood is used for bioenergy (fuel-switching) then the fact that CO_2 emissions from burning sustainably produced wood are not counted in assessing a country's net GHG emissions becomes important. The reason why they are not counted is that the emissions from burning will be balanced by growth. Over the cycle of tree growth, harvest and burning, there will be no net emissions, implying that the carbon sequestration should only be counted as a credit if the emissions from burning the wood are counted as a debit. Where a new forest is planted, as with afforestation, this further implies that only carbon credits for the first planting would be received — subsequent sequestration from planting and emissions from burning would balance and would provide neither carbon sequestration credits nor emission debits.

At this point there are varying opinions, domestically and internationally, on these issues which will only be resolved through international negotiations. Resolution will hopefully occur by 2001. The greater likelihood that block plantations will be harvested as compared to shelterbelts means that these issues are of much greater significance for the former, especially when fast-growing species are used. The use of fast-growing species means that these issues will be important as early as the first commitment period. Note, however, that trees in shelterbelts eventually die, which may raise the same issues as harvesting, unless the shelterbelt becomes an uneven-aged stand in permanent tree cover.

In the long-run, net carbon sequestration benefits over and above carbon storage in forest products will only occur on lands that are permanently converted to forests. Where the land is only temporarily converted to forests, the ultimate deforestation debit will, in all likelihood, cancel out the previously obtained afforestation credit. In other words, a temporary conversion of land to forests will produce long-term carbon credits only to the extent that the credits are recognized for the storage of carbon in forest products. These credits are not included in our analysis since they are not

part of the Kyoto Protocol at present. Thus, based on the Kyoto Protocol as it now stands, temporary afforestation simply 'borrows' carbon credits against future debits.

Assessing the Cost Effectiveness of Afforestation

For emission-reducing actions, cost effectiveness is measured as the net present value of lifetime costs of the action over the lifetime emissions reduction. The application of this approach to carbon sequestration poses problems related to the dynamic and long-term impacts of afforestation actions. These actions are characterized by large up-front costs and carbon sequestration benefits which are a function of time. The carbon benefits are initially low, and this will certainly be true in the first commitment period, but they can become very substantial after several decades. As well, the 'lifetime' of the action is unclear. Using different time periods in the cost-effectiveness calculation can give very different results. Accordingly, we decided to present two sets of estimates as was shown in summary Table 3.2.1. Both use the full cost of afforestation but one uses only the carbon sequestered in the first commitment period while the other uses the total carbon sequestered over 2000-2050. The second set does not account for the possible reconversion of land back to agricultural uses (deforestation) and the carbon debits that would then result, nor does it account for the effects on carbon of harvesting followed by regeneration of the forest. This is especially relevant for the fast-growing plantation action.

The long time periods involved also raise the issue of discounting the physical carbon, just as dollar values are discounted. Following the advice of the Analysis and Modelling Group, we have not discounted the carbon sequestered, though the largest annual sequestration benefit from afforestation could come 30 or more years in the future, depending on the species chosen and the planting schedule. By not discounting, the assumption is that the benefit of carbon sequestered in the future is the same as carbon sequestered now. There are two related aspects of this assumption. First, it means that, in terms of slowing climate change, sequestering carbon well into the future has the same impact on global warming as does sequestering in the near future.

The second aspect concerns the optimal way to make investments to reduce Canada's net emissions in the near term (i.e. in the next 10 to 20 years), and especially to meet Canada's commitment for 2008-2012. This is a question of determining the most cost-effective investments in emissions reduction and sequestration, a key goal of the National Implementation Strategy. When cost effectiveness is calculated using sequestration over a lengthy period, and carbon is not discounted, the effect is to increase the cost effectiveness of sequestration actions relative to other actions, even though the sequestration could be relatively less cost effective in terms of helping to achieve Canada's target in the first few commitment periods. Another point of view is that afforestation is a hedge against more costly emission reduction actions that may be necessary in the future as initial relatively low-cost actions are exhausted. The argument here is that, while apparently costly relative to other actions that could be initiated in the short to medium term, in the longer term afforestation will prove useful, but only if the action is taken now.

3.2.2 Impediments to Afforestation and Policy Considerations

Impediments to Afforestation

Each afforestation action faces similar impediments. The major impediments are summarized here, based in part on the discussion in the previous section:

- Negotiation outcomes, including the definition of afforestation and what carbon stocks will be counted, are uncertain. As well, there is a possibility that shelterbelts may not be included in the agreed-upon definition of afforestation - this will not be known until late 2000, at the earliest.
- Afforestation has a significant up-front cost for planting and maintenance, as well as opportunity costs for the land diverted to growing trees. In contrast, benefits from using the trees for purposes other than carbon will occur in the future, perhaps not for three or four decades if slower-growing species are used.
- There will be significant transaction costs to develop, implement and operate afforestation programs, including the systems needed to measure, monitor and verify sequestration and emissions.

- While Canada has a very large area of land that could be afforested, the land actually available for afforestation is likely much more limited. This is, in part, a function of market opportunities available to landowners and the level of incentives provided.

General policies and mechanisms to overcome these impediments generally do not differ from one afforestation action to another, and so we summarize them here rather than repeating them for each action. While this section describes various policies and mechanisms, the Forest Sector and Sinks Tables emphasize that more analysis is required to specify detailed afforestation program characteristics, targets and costs. The scale of the afforestation actions being considered here far exceeds any previous Canadian, and most international, efforts. A prudent approach is to start at a modest scale with a focus on the most cost-effective opportunities, and expand as experience is gained. As already explained, we include a moderate ramp-up period (2000-2005) to account for the time it will take to start up afforestation programs. This will also allow some time for experience to be gained, but an even slower approach could be chosen.

Mobilization of a Variety of Participants in Afforestation

The above discussion of participation rates and costs focussed on landowners since it is their land that will be planted. However, when considering how best to encourage afforestation, we need to consider both the potential revenues and other benefits of afforestation, and the potential motivations and roles of a variety of possible participants in afforestation efforts other than landowners (see Table 3.2.4). While commercial considerations and returns are one major motivation of involvement of many participants, it should be borne in mind that many other potential motivations exist.

In the previous section, it was made clear that the single greatest impediment to achieving afforestation actions is likely to be achieving the necessary participation rates. **If we assume that the landowner bears all of the three costs described above, then the total cost represents the level of incentive that will have to be provided to him or her to participate in afforestation, in the absence of any benefits from the afforestation.**

Table 3.2.4
Participants in Afforestation Efforts

Participant	**Potential Roles**	**Motivations**	**Requirement for Involvement**	**Afforestation Program**
Participants whose land will be affected				
Farmers (including woodlot owners)	Provide land; may be involved in establishment and management	Financial return or at least no financial loss, maintain or improve the land (e.g. aesthetics, soil conservation, biodiversity, forest restoration)	A financial return at least equal to current revenue from land, if any, after accounting for risks; clear indication that land will be improved	Block plantations, shelterbelts, tree planting
Other landowners (e.g. recreational owners), including woodlot owners	Provide land; may be involved in establishment and management	Maintain or improve the land (e.g. aesthetics, soil conservation, biodiversity, forest restoration)	Clear indication that land will be improved; compensation for planting costs	Small block plantations, shelterbelts, tree planting

Participants who act as intermediaries				
Brokers, managers	Connect interested parties; may manage plantations; may provide some investment	Financial return	Financial return at least equivalent to other possible investments, after accounting for risks; carbon trading system	Block plantations
Investors with only financial motivations	Investment	Financial return	Financial return at least equivalent to other possible investments	Block plantations
Participants with a direct interest in the carbon, wood or environmental benefits of afforestation				
Federal and provincial governments	Investment (via incentives, favourable tax treatment); establish standards, carbon trading system; establish measurement, monitoring, verification systems	Help meet Canada's emission reduction commitment; rural employment; maintain or improve the land (e.g. aesthetics, soil conservation, biodiversity, forest restoration)	Cost effective (relative to other potential actions) and politically acceptable; clear indication that land will be improved	Block plantations, shelterbelts, tree planting
Companies, municipalities (may also own the land)	Investment (and favourable tax treatment in case of municipalities)	Carbon to offset their own emissions	Cost effective; recognition of the carbon as a legitimate offset for their emissions	Block plantations, shelterbelts, tree planting
Forest products companies, energy companies (may also own the land)	Investment, management	Supply of fibre for existing or potential uses	Supply that is economic relative to other supply sources (existing timber for forest products companies; other energy sources for energy companies)	Block plantations, shelterbelts
Municipalities, environmentally concerned citizens, ENGOs	Some investment, planting labour and other "free" services	Aesthetics; environmental concerns (biodiversity, soil conservation, reducing climate change, habitat)	Clear indication that environmental goals will be met	Shelterbelts, tree planting, block plantations (?)

There are likely to be differences between block plantations and shelterbelts in the magnitude of the incentive required. Block plantations generally will require a much larger area commitment from individual landowners than will shelterbelts. The latter generally will occur on a relatively small part of a farm. In contrast, the scale of block planting might result in a farm losing its farm status, with a consequent loss of favourable tax treatment under current regulations. This implies that larger or different incentives may be needed for block plantations than for shelterbelts but we have not taken this into account in the analysis.

One way for the incentive to be disbursed is for governments to pay all of it, whether in the form of direct payments, tax expenditures or through the provision of free seedlings and direct assistance to the landowner. Governments also will have to bear various other afforestation program costs, including the cost of marketing, educational material, technical support, measurement and monitoring of afforestation and carbon sequestration performance, verification of sequestration performance for giving carbon credits, and administration of incentive mechanisms. At the same time, there are also important spin-off benefits from afforestation that should be of interest to governments, such as potential contributions to rural diversification and employment.

While government could pay for afforestation in its entirety, the Forest Sector and Sinks Tables believe that afforestation efforts need not be funded solely by government. This is because afforestation has at least three benefits (other than helping to meet Canada's Kyoto commitment, a key interest for governments) that could be of interest to landowners or to other participants.

1. Although landowners will be changing the current use of their land when they afforest it, the wood may be a source of future revenue when and if it is used for forest products or bioenergy. The current value of the future harvest will depend on the species grown, how long in the future the harvest occurs and future prices. Current interest in afforestation for forest products or bioenergy is limited due to relatively inexpensive alternatives (timber from public lands, low-cost fossil fuels) and afforestation for these purposes likely will require fast-growing species on sites with good productivity for growing trees (though the sites may be of lower productivity for agricultural purposes). This will increase initial costs but also result in an earlier return on the afforestation investment. As already discussed, though, the future harvesting of afforested areas raises important issues about accounting for the loss of carbon that still need to be resolved in international negotiations.

   We did not include estimates of future revenues for forest products or bioenergy in calculating the cost of the afforestation actions. In most cases, including these revenues will not reduce the estimated present value of the costs significantly. This is because the discounted future value of the afforested areas for forest products or bioenergy reflects two offsetting effects. As the trees grow, their commercial value (e.g. for forest products) increases but this is largely offset by the effect of discounting to obtain the present value in 2000. The value of the trees for commercial purposes can be proxied by applying current regional stumpage rates (payments made to provincial governments for timber harvested on public land) to the standing merchantable tree volume at any given point in time. Applying these rates to the proposed afforestation actions involving traditional tree species (i.e. a total area of 793,000 ha excluding the fast-growing plantation action) results in a commercial present value of 1997$3 million for the areas afforested by 2010, using a 10% discount rate. If a 6% discount rate is used, which is a common approach to valuing timberland, the present value is about 1997$4 million. While the tree volume will be substantially larger in 2030, the effect of the discounting is such that its present value will have increased to only 1997$4 to $12 million depending upon the discount rate. Accounting for this value has only a marginal impact on the net cost of afforestation using traditional slower growing species.

   However, accounting for the value of the afforested area for forest products or bioenergy has a larger impact when fast-growing species are used, since tree growth rates are much faster and harvesting occurs much sooner. We provide a sensitivity analysis on this subject in the discussion of the fast-growing plantation action.

2. The carbon itself will have a value that will reflect the future demand for and supply of carbon credits, which in turn will be a function of the cost of alternative emission reducing and carbon sequestration possibilities available domestically and internationally. Whether landowners can obtain this value will depend on the systems created for domestic carbon trading. They may also need to bear costs associated with obtaining value from the carbon because of the need to measure sequestration if the carbon is to be bought and sold. And again, the possibility of responsibility for debits associated with the afforestation must be considered, whether through loss of carbon from natural causes, harvesting or deforestation. **We did not account for the value of credits obtained for sequestration or emission reductions in any of the actions analysis.**

3. Afforestation will have many other benefits to landowners or others related to forest restoration, habitat enhancement, soil conservation, water quality, aesthetics, protection from wind and the sun, and other environmental non-monetary benefits. Some owners may be willing to absorb some of the planting, maintenance, protection and opportunity costs themselves because of the value they place on these benefits. For example, if a landowner places a high value on increased biodiversity that might result from afforestation, he or she could require less incentive to afforest than another owner who was solely interested in financial returns. **We did not quantify these non-financial benefits.**

Incentives likely will be needed to encourage the involvement of many participants interested in these benefits, but the Forest Sector and Sinks Tables believe that the mobilization of other participants could be the most cost-effective way to achieve afforestation targets.

As well as those interested in environmental benefits, carbon or harvesting, there could also be scope to involve potentially large areas which undergo regular vegetation management (e.g. cutting grass) and for which planting trees could be an alternative. These include electric utility transmission corridors, highway corridors, municipal land-fill areas that have reached their capacity, areas in commercial and industrial parks, and areas around de-commissioned mines and quarries. Planting trees may be a cost-effective alternative to periodic vegetation management in some of these areas, especially if the value of the additional carbon can be obtained.

Creating a market for carbon in which trading of carbon from afforestation is included will have a large impact on the economics of afforestation, as it might for energy and efficiency actions. A carbon market could create proponents who are willing to invest in afforestation in expectation of using or selling the carbon. The greater the value of carbon, the less the incentive that will have to be provided for afforestation, provided that landowners or other investors in afforestation can obtain the carbon value. However, monitoring and verification systems required for afforestation are likely to be more detailed and costly when the carbon can be traded, especially if the measurement, monitoring and verification must be done for each individual afforested area.

Potential Policies to Encourage Afforestation

Table 3.2.5 on the following page summarizes a variety of possible policies and mechanisms that could be part of an afforestation program or programs to encourage block plantations and shelterbelts.

Table 3.2.5
Impediments and Possible Policies for Block Plantation and Shelterbelt Afforestation

Impediments to Implementation	Potential Policies As Part of Afforestation Program (s)
1. **Lack of knowledge about afforestation, site selection, species selection, and concern about impacts on land**	**1.1 Technical assistance and information at no cost** Responsibility: Federal government, provincial governments, probably through existing mechanisms such as PFRA in Prairies; woodlot owner associations, forestry associations Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown **1.2 Program to market afforestation** Responsibility: Federal government, provincial governments, woodlot owner associations, forestry associations Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown **1.3 Encourage/sponsor development of landowner afforestation associations as a source of information and assistance.** Responsibility: Federal government, provincial governments Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown
2. **Loss of landowner revenue from existing land use**	**2.1 One-time per hectare payment, 50% paid upon planting and commitment to afforestation for a specified period, with the remainder paid upon successful establishment ('free-to-grow' stage).** Maximum payment could be proxied by appraised or market land values. Commitment period depends, in part, on species. Responsibility: Federal and provincial governments, through existing mechanisms where possible; companies, municipalities or others with an interest in securing carbon or fibre; joint funding arrangements with governments could be made as a way of attracting greater involvement of companies Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Depends on location and previous use of land, as well as the duration of the commitment of the landowner; may range from \$0/ha to \$1,000/ha **2.2 Annual land rental payments upon commencement of afforestation activity, with a commitment to afforestation for a specified period.** Commitment period depends, in part, on species. Responsibility: Federal and provincial governments, through existing mechanisms where possible; companies, municipalities or others with an interest in securing carbon or fibre; joint funding arrangements with governments could be made as a way of attracting greater involvement of companies Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Depends on location and previous use of land; may range from \$0/ha to \$100/ha per year

	2.3 One-time per hectare payment to add a conservation easement to the deed for the land. The easement would create a requirement to maintain forest cover and/or create a restriction on certain activities such as harvesting or deforestation. The easement would be permanent in that it would not change with change in ownership. Responsibility: Federal and provincial governments Timeframe: Initiate in 2000 Cost: Depends on location and previous use of land, may range from $100/ha to $3,000/ha **2.4 Make funds received for afforestation partially tax deductible through tax credits.** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000 Cost: Unknown tax expenditure **2.5 Establish market for carbon credits which includes carbon from afforestation, in which landowners, other investors in afforestation, and those interested in using afforestation carbon credits, can trade** Responsibility: Federal and provincial governments Timeframe: As soon as possible Cost: Unknown
3. Costs to landowner or others who undertake the planting and maintenance	**3.1 Full or partial (50-75%) compensation to landowners, who bear all annual costs related to establishment and maintenance, up to a specified maximum payment per year per farm.** Responsibility: Federal and provincial governments, through existing mechanisms where possible; companies, municipalities or others with an interest in securing carbon or fibre; joint funding arrangements with governments could be made as a way of attracting involvement of companies Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Will depend on a variety of factors including location, type of afforestation, species; may range from $500/ha to $3,500/ha, spread over several years, for full compensation **3.2 Seedlings at low cost (10-25%) or no cost** Responsibility: Federal and provincial governments, through existing mechanisms where possible; companies, municipalities or others with an interest in securing carbon or fibre; joint funding arrangements with governments could be made as a way of attracting involvement of companies Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Will depend on species used and availability - typical seedling cost is $200-400/ha

	3.3 Labour provided, or costs paid fully or partially Responsibility: Federal and provincial governments, through existing mechanisms where possible including employment programs; companies, municipalities or others with an interest in securing carbon or fibre; joint funding arrangements with governments could be made as a way of attracting involvement of companies Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Will depend on labour rates and characteristics of the site Preparation, planting and maintenance - may be $500 To 2,500/ha **3.4 Change taxation regulations to make non-funded afforestation expenses deductible in the year in which they occur, or otherwise treat planting trees as a (long-term) agricultural crop** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000 Cost: Unknown tax expenditure **3.5 Make funds received for afforestation partially tax deductible through tax credits.** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000 Cost: Unknown tax expenditure **3.6 Change property tax systems to make taxes on afforested land similar to those for agricultural land** Responsibility: Municipal and provincial governments Timeframe: Initiate in 2000 Cost: Unknown tax expenditure
4. Shortage of seedling stock of species required for afforestation	**4.1 Provide grants or low-interest loans for investments in nursery capacity** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown
5. Uncertainty about sequestration potential and measurement, monitoring and verification	**5.1 Additional incentives to early landowner participants who act as pilot projects to help confirm growth and yield, especially of young trees** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown **5.2 Additional incentives to early landowner participants who act as pilot projects to help develop sequestration measurement, monitoring and verification protocols** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown **5.3 Minimum carbon sequestration guarantees for early afforestation projects to landowners and others who invest because of the potential value of carbon** Responsibility: Federal and provincial governments Timeframe: Initiate in 2000, as part of afforestation program(s) Cost: Unknown

3.2.3 Action: Plantations of Fast-Growing Species

ACTION:	***Plant 50,000 hectares of private land across Canada over five years (2001-2005), using fast-growing tree species.***

The action assumes that 50,000 ha of privately owned land could be planted across Canada using fast-growing tree species, at a rate of 10,000 ha per year from 2001-2005. The analysis is based on planting hybrid poplar but other species, such as willow, could be used. Hybrid poplar stands will begin to break up naturally by about age 30 and decay rapidly. There is little data on the collapse of poplar stands but it is likely that by age 50 a stand will be almost completely broken up and that poplar tree biomass carbon will be minimal.

As well as sequestering carbon, the trees could have other end uses. One possible end use is as a nurse crop. In some parts of the country, such as southern Ontario, planting hybrid poplars on unused agricultural land would provide the conditions needed to encourage a transition to native hardwood forests which would sequester carbon over a much longer period than would the hybrid poplars. The forest products and energy industries could be very interested in planting and harvesting fast-growing plantations for use in forest products, such as pulp and oriented strand board, or for bioenergy.

There is a growing commercial interest in hybrid poplar plantations on the part of the forest products industry in Canada and the United States, as discussed in the previous section. Typical harvesting ages are 12 to 15 years in Canada. This would mean that areas planted in 2001 will be harvested in 2012-2015. Thus harvesting will begin either at the end of the first commitment period or immediately afterward. This raises the issue of the time path of carbon credits and potential debits. The potential for carbon debits is related to how harvesting of afforested areas and the storage of carbon in forest products are treated in the Kyoto Protocol. The issues were discussed above, where it was noted that there are varying views on these questions. If harvesting does not count as a debit then no issues arise. On the other hand, if the Protocol does require accounting for debits from harvesting afforested areas then the time path of the credits and debits becomes important.

3.2.3 Action: Plantations of Fast-Growing Species

ACTION:	***Plant 50,000 hectares of private land across Canada over five years (2001-2005), using fast-growing tree species.***

The action assumes that 50,000 ha of privately owned land could be planted across Canada using fast-growing tree species, at a rate of 10,000 ha per year from 2001-2005. The analysis is based on planting hybrid poplar but other species, such as willow, could be used. Hybrid poplar stands will begin to break up naturally by about age 30 and decay rapidly. There is little data on the collapse of poplar stands but it is likely that by age 50 a stand will be almost completely broken up and that poplar tree biomass carbon will be minimal.

As well as sequestering carbon, the trees could have other end uses. One possible end use is as a nurse crop. In some parts of the country, such as southern Ontario, planting hybrid poplars on unused agricultural land would provide the conditions needed to encourage a transition to native hardwood forests which would sequester carbon over a much longer period than would the hybrid poplars. The forest products and energy industries could be very interested in planting and harvesting fast-growing plantations for use in forest products, such as pulp and oriented strand board, or for bioenergy.

There is a growing commercial interest in hybrid poplar plantations on the part of the forest products industry in Canada and the United States, as discussed in the previous section. Typical harvesting ages are 12 to 15 years in Canada. This would mean that areas planted in 2001 will be harvested in 2012-2015. Thus harvesting will begin either at the end of the first commitment period or immediately afterward. This raises the issue of the time path of carbon credits and potential debits. The potential for carbon debits is related to how harvesting of afforested areas and the storage of carbon in forest products are treated in the Kyoto Protocol. The issues were discussed above, where it was noted that there are varying views on these questions. If harvesting does not count as a debit then no issues arise. On the other hand, if the Protocol does require accounting for debits from harvesting afforested areas then the time path of the credits and debits becomes important.

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Table 3.2.6
Action Costs and GHG Impacts of Fast-Growing Plantations

	Estimate	Assumptions
Planting program		
· planting period	5 years	-program starts in 2000, with planting beginning in 2001
· area planted per year	10,000 ha/yr	-no ramp-up in activity: planting starts immediately at 10,000 ha/yr
· total planted	50,000 ha	
Incremental CO_2 sequestration		-includes above- and below-ground tree biomass only; emissions from fossil fuels used in planting are included in the estimates; net carbon sequestration on the land prior to the planting assumed to be zero; uses hybrid poplar growth curves
· 2010	1.31 Mt CO_2	
· 2000-2050, annual average	see note	
Costs		
· Average planting cost (1997$)	$3,395/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· Average annual opportunity cost (1997$)	$ 25/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$130.8 million	-uses a 10% discount rate
· NPV of opportunity cost (1997$)	$10.4 million	-uses a 10% discount rate, and based on payments for 25 years
· Cost effectiveness (1997$/tonne)		
· 2008-2012	$22.2/t CO_2	-using total non-discounted carbon sequestration (2008-2012)

Note: we assume that harvesting occurs at age 13 to 15 years and the area is replanted. Over the 2000-2050 period, the net carbon sequestration will depend either on the transition to a natural forest or on how harvesting of afforested areas and carbon in the resulting forest or fuel products are counted in the Protocol.

We assume that, if a plantation is harvested, it will be as part of a continual cycle of planting and harvesting for industrial purposes and that the long-term effect would be an increased carbon reservoir, especially if some of the carbon is stored in forest products. However, the net annual sequestration will vary over time as will the net credit that Canada can count. If this continual cycle does not occur (i.e. areas are not regenerated back to forest), then there would be a deforestation debit, reflecting the permanent conversion of the forest area back to another land-use.

The key point is that if fast-growing species are planted, there is a possibility that Canada will have to accept debits that will offset some of the credits as early as the first commitment period (because of the fast growth and relatively short lives of the trees). Of course, these same issues arise for all of the other plantation actions, but not for many decades in the future. For simplicity, in our analysis we assumed that no harvesting will occur in the first commitment period (harvesting occurs at age 13 to 15) so that the sequestration in the period is unambiguous and there is no possibility of a debit associated with harvesting. Earlier harvesting could reduce the net sequestration in the first commitment period. Over the 2000-2050 period, the net carbon sequestration will depend either on how the transition to a natural forest occurs or on how harvesting of afforested areas and carbon in the resulting forest products are treated in the Protocol.

If we assume that harvesting and carbon in forest products are not counted, as is currently the case in the Protocol, then any further carbon credits will depend on how afforestation and reforestation are defined. If they are defined using the IPCC definitions, then replanting of the harvested area will yield no further credit (but failure to replant will be deforestation and will yield a debit). In this case, the net effect will be the one-time credit equal to the initial afforestation.

Table 3.2.7
Regional Implications of Fast-Growing Plantations

Province	Land Planted ha	Mt CO_2 Sequestered 2010	NPV Planting and Opportunity Cost 1997$ millions	Cost Effectiveness 1997$/t CO_2 2008-2012
B.C.	5,000	0.16	14.1	18.1
Prairies	27,500	0.69	77.7	23.2
Ontario	7,500	0.20	21.2	21.8
Quebec	7,500	0.20	21.2	21.8
Atlantic	2,500	0.06	7.1	26.2
TOTAL	**50,000**	**1.31**	**141.2**	**22.2**

Regional areas for planting were chosen based on a rough assessment of the likely land availability and the current level of interest, which is highest in Alberta. Differences in sequestration and cost effectiveness across regions reflect assumptions about differences in growth curves. In general, the highest productivity is in southern B.C., with medium productivity in Eastern Canada and central B.C., and lower productivity in the Prairies.

When planting and opportunity costs are accounted for, the sequestration of 1.3 Mt CO_2 in 2010 has a cost effectiveness of 1997$22.2/t CO_2 in 2008-2012. If the plantations are harvested then the revenue from the use of the wood in forest products or bioenergy will partially offset these costs. If we assume that the trees are harvested at age 13, then three harvests are possible by 2050. Using a 10% discount rate results in a present value in 2000 for the harvests of 1997$14-27 million, where the lower figure is based on an estimated current bioenergy market price of 1997$4.6/$m^3$ of wood (net of logging and transportation costs) and the higher figure is based on an estimated forest products market price of 1997$9.7/$m^3$. Accounting for this revenue improves the cost effectiveness of the action from $22/t CO_2 to $18-20/t CO_2, but note that the possibility of carbon debits has not been accounted for.

3.2.4 Action: Shelterbelt Planting in the Prairie Provinces

ACTION:	***Plant shelterbelts on private land in the Prairie provinces each year from 2001-2015 (15 years), with a target planting rate of 13,000 ha per year.***

The action assumes that, as a first approximation, about 169,000 ha of privately owned land could be planted in shelterbelts over a 15-year period in the Prairie region. The annual target planting would be 13,000 ha per year with a ramp-up to the full target level between 2001 and 2005. This action builds on existing interest in, and programs to promote, shelterbelts, which have been planted in the Prairie provinces for many decades for the purposes of soil conservation and farmyard windbreaks. Much of this planting has been supported by the Prairie Farm Rehabilitation Administration (PFRA). At present at least 20,000 farms in the region have shelterbelts, averaging under 1.5 ha per farm. This action assumes that wide shelterbelts (four rows of trees) will be planted rather than the usual one to two rows, but a broader action could promote all types of shelterbelt planting (single row, multi-row, riparian, etc.). One advantage of shelterbelts is that they can be established as perimeter plantations without giving up entire fields, as would be the case with block plantations. A focus on shelterbelts therefore may increase the attractiveness of planting trees. However, shelterbelts could also have additional costs in the form of fencing to protect growing trees from livestock.

If we assume that harvesting and carbon in forest products are not counted, as is currently the case in the Protocol, then any further carbon credits will depend on how afforestation and reforestation are defined. If they are defined using the IPCC definitions, then replanting of the harvested area will yield no further credit (but failure to replant will be deforestation and will yield a debit). In this case, the net effect will be the one-time credit equal to the initial afforestation.

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Regional Implications of Fast-Growing Plantations

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Prairies	27,500	0.69	77.7	23.2
Ontario	7,500	0.20	21.2	21.8
Quebec	7,500	0.20	21.2	21.8
Atlantic	2,500	0.06	7.1	26.2
TOTAL	**50,000**	**1.31**	**141.2**	**22.2**

Regional areas for planting were chosen based on a rough assessment of the likely land availability and the current level of interest, which is highest in Alberta. Differences in sequestration and cost effectiveness across regions reflect assumptions about differences in growth curves. In general, the highest productivity is in southern B.C., with medium productivity in Eastern Canada and central B.C., and lower productivity in the Prairies.

When planting and opportunity costs are accounted for, the sequestration of 1.3 Mt CO_2 in 2010 has a cost effectiveness of 1997$22.2/t CO_2 in 2008-2012. If the plantations are harvested then the revenue from the use of the wood in forest products or bioenergy will partially offset these costs. If we assume that the trees are harvested at age 13, then three harvests are possible by 2050. Using a 10% discount rate results in a present value in 2000 for the harvests of 1997$14-27 million, where the lower figure is based on an estimated current bioenergy market price of 1997$4.6/$m^3$ of wood (net of logging and transportation costs) and the higher figure is based on an estimated forest products market price of 1997$9.7/$m^3$. Accounting for this revenue improves the cost effectiveness of the action from $22/t CO_2 to $18-20/t CO_2, but note that the possibility of carbon debits has not been accounted for.

3.2.4 Action: Shelterbelt Planting in the Prairie Provinces

ACTION:	***Plant shelterbelts on private land in the Prairie provinces each year from 2001-2015 (15 years), with a target planting rate of 13,000 ha per year.***

The action assumes that, as a first approximation, about 169,000 ha of privately owned land could be planted in shelterbelts over a 15-year period in the Prairie region. The annual target planting would be 13,000 ha per year with a ramp-up to the full target level between 2001 and 2005. This action builds on existing interest in, and programs to promote, shelterbelts, which have been planted in the Prairie provinces for many decades for the purposes of soil conservation and farmyard windbreaks. Much of this planting has been supported by the Prairie Farm Rehabilitation Administration (PFRA). At present at least 20,000 farms in the region have shelterbelts, averaging under 1.5 ha per farm. This action assumes that wide shelterbelts (four rows of trees) will be planted rather than the usual one to two rows, but a broader action could promote all types of shelterbelt planting (single row, multi-row, riparian, etc.). One advantage of shelterbelts is that they can be established as perimeter plantations without giving up entire fields, as would be the case with block plantations. A focus on shelterbelts therefore may increase the attractiveness of planting trees. However, shelterbelts could also have additional costs in the form of fencing to protect growing trees from livestock.

We assume shelterbelts will be planted in areas with soil productivity that is rated poor or medium for agricultural purposes — mainly in the southern half of the region — as these areas could benefit most from shelterbelts which reduce soil erosion and increase crop yields. Planting could be done in other areas as well. While soil productivity is not high, the areas planted will divert some land from crops and grazing, so that the land accessed likely will be more valuable than average marginal agricultural land. The action also assumes that incentives can be provided such that roughly 17% of farms in the Prairies will participate in shelterbelt planting of about 10 ha per farm. This is considered a very ambitious but achievable goal. If only 5 ha are planted per farm then about 35% of all farms would have to participate, a substantial participation rate.

Table 3.2.8
Action Costs and GHG Impacts of Prairie Shelterbelts

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	13,000 ha/yr	-five-year ramp-up to annual planting target by 2005
· total planting	169,000 ha	
Incremental CO_2 sequestration		-includes both above- and below-ground biomass; emissions from fossil fuels used in planting are included in the estimates; soil carbon sequestration is not included; net carbon sequestration prior to the shelterbelts is assumed to be zero
· 2010	0.15 Mt CO_2	
· 2000-2050, annual average	0.58 Mt CO_2/yr	
Costs		
· average planting cost (1997$)	$1,290/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· average annual opportunity cost (1997$)	$10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 98.7 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 8.5 million	-uses a 10% discount rate; annual payments made for 25 years
· cost effectiveness (1997$ / tonne)		
-2008 to 2012	$ 140.7/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 3.7/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

Species used in shelterbelts, and their shares in planting, will likely be chosen based on past success in shelterbelts and on species most likely to be available in existing nursery facilities. The analysis for this action assumed that future use of the wood was not a primary factor in determining species. Faster-growing species could be encouraged to maximize CO_2 in the initial commitment period, while other species would be more appropriate for sequestering in the long-term.

Table 3.2.9
Regional Implications of Prairie Shelterbelts

Province	Target Planting ha/yr	Mt CO_2 Sequestered 2010	Mt CO_2 Sequestered per year 2000-2050	NPV of Planting and Opportunity Costs 1997$ millions	Cost Effectiveness	
					1997$/t CO_2 2008-2012	1997$/t CO_2 2000-2050
Alberta	6,600	0.08	0.30	54.5	135.7	3.6
Saskatchewan	5,150	0.06	0.22	42.4	148.6	3.8
Manitoba	1,250	0.01	0.06	10.3	137.6	3.6
TOTAL	**13,000**	**0.15**	**0.58**	**107.2**	**140.7**	**3.7**

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the assumption regarding planting schedule (e.g. a delay in planting to 2005 reduces sequestration in 2010 from 0.15 Mt CO_2 to 0.05 Mt CO_2). Irrespective of when planting starts, carbon sequestration will continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the above Table.

Planting costs for shelterbelts will vary widely from site to site and are uncertain because, to date, shelterbelt planting programs have relied to a large degree on volunteer labour and free plants. Opportunity costs are very uncertain. We have assumed an opportunity cost of $10/ha/yr, well below the average annual rental value of farmland in the Prairie provinces, which is about $100-120/ha/yr. Shelterbelts would most likely be done on land with below-average value for agricultural purposes but using a figure of $100/ha/yr rather than $10/ha/yr shows the sensitivity of our results to the opportunity cost assumption. Using the higher figure raising the cost per tonne to $210/t CO_2 in the first commitment period and $5.5/t CO_2 over 2000-2050. The regional differences reflect differences in the land area considered to be available, the distribution of species planted and the areas of medium and poor soil productivity land that are planted.

Prairie Farm Rehabilitation Administration' Shelterbelts Program

The Prairie Farm Rehabilitation Administration (PFRA) supports a longstanding shelterbelt program on the prairies. Bands of trees and tall shrubs are planted along the margins of farm fields and around farm buildings. PFRA grow and supply the tree and shrub stock, and the producer covers the shipping and planting costs (average $0.03 per tree or shrub) (Kort, 1999). Recent estimates (Turnock, 1999) of the carbon sequestration potential of planted shelterbelts at historic rates since 1990, suggest that if shelterbelt planting continues, up to 0.36 Mt of CO_2 per year could be sequestered in the first commitment period. Based on 142,144,400 trees and tall shrubs that have been distributed, and those projected for distribution from 1990 to 2012, a total of above 76,000 hectares would be planted corresponding to 3,400 ha/yr on average (Kort, 1999).

There seems to be no overlap between this and the shelterbelt planting action described in this section. However, the PFRA-type has not been added up with the other measures since no proper analysis was conducted. The major differences between the two sequestration estimates observed include the following: the PFRA planting densities are higher, the survival rates (70%), and include 20 tree and shrub species many of which are fast growing relative to traditional species used in forestry. Turnock's calculations are based on a species-specific equation developed by PFRA from carbon gain data gathered for common tree and shrub species. Below-ground carbon sequestration was not included in Turnock's estimate.

3.2.5 Action: Block Plantations in the Prairie Provinces

ACTION:	***Plant block plantations on private land in the Prairie provinces each year from 2001-2015 (15 years), with a target planting rate of 20,000 ha per year.***

This action assumes that, as a first approximation, about 260,000 ha of privately owned land could be planted in block plantations over a 15-year period in the Prairie region. The annual target planting would be 20,000 ha per year, with a ramp-up to the full annual planting target by 2005. This action requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and convert them to tree plantations. Block plantations would vary in size depending on individual farm size and landowner interest.

We assume that efforts to promote block plantations will be targeted to areas with soil productivity that are relatively good for growing trees, mainly in the southern half of the region. While soil productivity is fairly good for trees, the areas planted may not always require diversions of land from crops and grazing because planting marginal agricultural land (that is, land not used or with little suitability for agricultural uses) will be the main objective. Tree species used in block plantations, and their shares in planting, will be determined based on expectations as to the best possible uses of the plantation in the future, whether for environmental purposes (forest restoration, habitat etc.), forest products or energy. The analysis for this action did not take this into account explicitly.

Table 3.2.10
Action Costs and GHG Impacts of Prairie Block Plantations

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	20,000 ha/yr	-five-year ramp-up to annual planting target by 2005
· total planting	260,000 ha	
Incremental CO_2 sequestration		-includes both above- and below-ground biomass; emissions from fossil fuels used in planting are included in the estimates; soil carbon sequestration is not included; net carbon sequestration prior to the plantations is assumed to be modest and is subtracted from the sequestration due to the action
· 2010	0.37 Mt CO_2	
· 2000-2050, annual average	1.43 Mt CO_2/yr	
Costs		
· average planting cost (1997$)	$ 1,650/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· average annual opportunity cost (1997$)	$ 10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 201.1 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 13.1 million	-uses a 10% discount rate, with payments made for 25 years
· cost effectiveness 1997$/tonne		
-2008 to 2012	$ 114.6/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 3.0/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

3.2.5 Action: Block Plantations in the Prairie Provinces

ACTION:	***Plant block plantations on private land in the Prairie provinces each year from 2001-2015 (15 years), with a target planting rate of 20,000 ha per year.***

This action assumes that, as a first approximation, about 260,000 ha of privately owned land could be planted in block plantations over a 15-year period in the Prairie region. The annual target planting would be 20,000 ha per year, with a ramp-up to the full annual planting target by 2005. This action requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and convert them to tree plantations. Block plantations would vary in size depending on individual farm size and landowner interest.

We assume that efforts to promote block plantations will be targeted to areas with soil productivity that are relatively good for growing trees, mainly in the southern half of the region. While soil productivity is fairly good for trees, the areas planted may not always require diversions of land from crops and grazing because planting marginal agricultural land (that is, land not used or with little suitability for agricultural uses) will be the main objective. Tree species used in block plantations, and their shares in planting, will be determined based on expectations as to the best possible uses of the plantation in the future, whether for environmental purposes (forest restoration, habitat etc.), forest products or energy. The analysis for this action did not take this into account explicitly.

Table 3.2.10
Action Costs and GHG Impacts of Prairie Block Plantations

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	20,000 ha/yr	-five-year ramp-up to annual planting target by 2005
· total planting	260,000 ha	
Incremental CO_2 sequestration		-includes both above- and below-ground biomass; emissions from fossil fuels used in planting are included in the estimates; soil carbon sequestration is not included; net carbon sequestration prior to the plantations is assumed to be modest and is subtracted from the sequestration due to the action
· 2010	0.37 Mt CO_2	
· 2000-2050, annual average	1.43 Mt CO_2/yr	
Costs		
· average planting cost (1997$)	$ 1,650/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· average annual opportunity cost (1997$)	$ 10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 201.1 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 13.1 million	-uses a 10% discount rate, with payments made for 25 years
· cost effectiveness 1997$/tonne		
-2008 to 2012	$ 114.6/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 3.0/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the planting schedule (e.g. a delay in planting to 2005 reduces sequestration in 2010 from 0.37 Mt CO_2 to 0.14 Mt CO_2). Irrespective of when planting starts, carbon sequestration would continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the previous Table.

Opportunity costs are a major area of uncertainty. We have assumed an opportunity cost of $10/ha/yr, well below the average annual rental value of farmland in the Prairie provinces, which is about $100-120/ha/yr. Block plantations would most likely be done on land with below-average value for agricultural purposes, but using a figure of $100/ha/yr rather than $10/ha/yr shows the sensitivity of our results to the opportunity cost assumption. Using the higher figure raises the cost per tonne to $177/t CO_2 in the first commitment period and $4.6/t CO_2 over 2000-2050.

Table 3.2.11
Regional Implications of Prairie Block Plantations

Province	Planting Target ha/yr	Mt CO_2 Sequestered 2010	Mt CO_2 Sequestered per year 2000-2050	NPV of Planting and Opportunity Costs 1997$ millions	Cost Effectiveness 1997$/t CO_2 2008-2012	Cost Effectiveness 1997$/t CO_2 2000-2050
Alberta	8,700	0.16	0.62	93.4	114.6	3.0
Saskatchewan	7,650	0.14	0.55	82.0	114.6	3.0
Manitoba	3,650	0.07	0.26	38.8	114.6	3.0
TOTAL	**20,000**	**0.37**	**1.43**	**214.2**	**114.6**	**3.0**

Cost effectiveness does not vary by province, as the same quality of land and mix of species is assumed to be used in each province for this action.

3.2.6 Action: Block Plantations in British Columbia

ACTION:	***Plant block plantations on private land in British Columbia each year from 2001-2015 (15 years), with a target planting rate of 13,000 ha per year.***

The action assumes that, as a first approximation, about 169,000 ha of privately owned land could be planted in shelterbelts over a 15-year period in B.C. The annual target planting would be 13,000 ha per year with a ramp-up to the annual planting target by 2005. The focus of this action is privately owned agricultural land that is considered under-utilized, unused or marginal. While block plantations are the focus of this action, some of the planting could be in shelterbelts. Thus, this action generally requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and converting them to tree plantations. Block plantations would vary in size depending on individual farm size, land quality/productivity and landowner interest. In calculating the carbon sequestration, we used species commonly used in reforestation in Canada. In practice, the actual species chosen will reflect decisions as to the preferred uses, including for carbon, other environmental benefits, forest products or energy.

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the planting schedule (e.g. a delay in planting to 2005 reduces sequestration in the first commitment period by over 50%). Irrespective of when planting starts, carbon sequestration would continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the above Table. Planting costs will vary widely from site to site and are uncertain.

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the planting schedule (e.g. a delay in planting to 2005 reduces sequestration in 2010 from 0.37 Mt CO_2 to 0.14 Mt CO_2). Irrespective of when planting starts, carbon sequestration would continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the previous Table.

Opportunity costs are a major area of uncertainty. We have assumed an opportunity cost of $10/ha/yr, well below the average annual rental value of farmland in the Prairie provinces, which is about $100-120/ha/yr. Block plantations would most likely be done on land with below-average value for agricultural purposes, but using a figure of $100/ha/yr rather than $10/ha/yr shows the sensitivity of our results to the opportunity cost assumption. Using the higher figure raises the cost per tonne to $177/t CO_2 in the first commitment period and $4.6/t CO_2 over 2000-2050.

Table 3.2.11
Regional Implications of Prairie Block Plantations

Province	Planting Target ha/yr	Mt CO_2 Sequestered 2010	Mt CO_2 Sequestered per year 2000-2050	NPV of Planting and Opportunity Costs 1997$ millions	Cost Effectiveness	
					1997$/t CO_2 2008-2012	1997$/t CO_2 2000-2050
Alberta	8,700	0.16	0.62	93.4	114.6	3.0
Saskatchewan	7,650	0.14	0.55	82.0	114.6	3.0
Manitoba	3,650	0.07	0.26	38.8	114.6	3.0
TOTAL	**20,000**	**0.37**	**1.43**	**214.2**	**114.6**	**3.0**

Cost effectiveness does not vary by province, as the same quality of land and mix of species is assumed to be used in each province for this action.

3.2.6 Action: Block Plantations in British Columbia

ACTION:	***Plant block plantations on private land in British Columbia each year from 2001-2015 (15 years), with a target planting rate of 13,000 ha per year.***

The action assumes that, as a first approximation, about 169,000 ha of privately owned land could be planted in shelterbelts over a 15-year period in B.C. The annual target planting would be 13,000 ha per year with a ramp-up to the annual planting target by 2005. The focus of this action is privately owned agricultural land that is considered under-utilized, unused or marginal. While block plantations are the focus of this action, some of the planting could be in shelterbelts. Thus, this action generally requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and converting them to tree plantations. Block plantations would vary in size depending on individual farm size, land quality/productivity and landowner interest. In calculating the carbon sequestration, we used species commonly used in reforestation in Canada. In practice, the actual species chosen will reflect decisions as to the preferred uses, including for carbon, other environmental benefits, forest products or energy.

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the planting schedule (e.g. a delay in planting to 2005 reduces sequestration in the first commitment period by over 50%). Irrespective of when planting starts, carbon sequestration would continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the above Table. Planting costs will vary widely from site to site and are uncertain.

Table 3.2.12
Action Costs and GHG Impacts of British Columbia Block Plantations

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	13,000 ha/yr	-5-year ramp-up to annual planting target by 2005
· total planting	169,000 ha	
Incremental CO_2 sequestration		-includes both above-and below-ground biomass; emissions from fossil fuels used in planting are included in the estimates; soil carbon sequestration is not included; net carbon sequestration prior to the plantations is not accounted for
· 2010	0.04 Mt CO_2	
· 2000-2050, annual average	0.70 Mt CO_2/yr	
Costs		-includes costs of site preparation, seedlings, follow-up care and labour
· Average planting cost (1997$)	$1,027/ha	
· Average annual opportunity cost (1997$)	$10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 77.1 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 8.5 million	-uses a 10% discount rate; payments made for 25 years
· cost effectiveness 1997$/tonne		
-2008 to 2012	$ 452.5/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 2.4/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

The effect of differences in growth curves can be seen when the results for this action are compared to the results for the other afforestation actions. The curves uses for this action tended to show slower growth in the early decades after growth, but faster growth in later decades. In part this reflects real differences in growth rates in B.C., especially on the coast, compared to other parts of Canada. However, an unknown part of the difference is simply a reflection of lack of good knowledge about growth curves for plantations and for the first few decades of growth.

British Columbia is more varied physically and biologically than any other province in Canada and there are major differences across the province. This action assumes that these intra-provincial differences in suitability for and productivity of plantations are taken into account through species selection and the distribution of planting across the province. Most of the land planted is in the interior where tree growth is slower (close to 90% of planted land), reflecting the availability of land. While only about 10% of the planted land is on the coast, it accounts for 30% of the average annual carbon sequestration in the first commitment period, reflecting higher productivity.

3.2.7 Action: Block Plantations in Eastern Canada

ACTION:	***Plant block plantations in Eastern Canada each year from 2001 to 2015 (15 years) with a target planting rate of 15,000 ha per year.***

This action assumes that, as a first approximation, about 195,000 ha of privately owned land could be planted in block plantations over a 15-year period — 78,000 ha in Ontario, 78,000 ha in Quebec and 39,000 ha in the Atlantic provinces. The annual target planting would be 15,000 ha per year, with a ramp-up to the annual planting target by 2005. This action requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and converting them to tree plantations. Block plantations would vary in size depending on individual farm size and landowner interest. The 78,000 ha target for Ontario is about 50% higher than the land planted under the *Ontario Woodlands Improvement Act* which was in force for two decades from the mid-1960s to the mid-1980s. For the purpose of developing this option, specific tree species and their distribution were selected. Final species composition will be determined based on expectations as to the best possible uses of the plantation in the future, whether for environmental purposes, forest products or energy.

Table 3.2.13
Action Costs and GHG Impacts of Eastern Canadian Block Plantations

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	15,000 ha/yr	-5-year ramp-up to annual planting target by 2005
· total planting	195,000 ha	
Incremental CO_2 sequestration		-includes both above- and below-ground biomass and soil carbon;
· 2010	0.22 Mt CO_2	
· 2000-2050, annual average	1.37 Mt CO_2/yr	-emissions from fossil fuels used in planting are excluded from the estimates; net carbon sequestration prior to the plantations is assumed to be zero
Costs		
· average planting cost (1997$)	$ 1,500/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· average annual opportunity cost (1997$)	$ 10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 147.2 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 9.8 million	-uses a 10% discount rate; payments made for 25 years
· cost effectiveness 1997$/tonne		
-2008 to 2012	$ 144.9/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 2.3/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

3.2.7 Action: Block Plantations in Eastern Canada

ACTION:	***Plant block plantations in Eastern Canada each year from 2001 to 2015 (15 years) with a target planting rate of 15,000 ha per year.***

This action assumes that, as a first approximation, about 195,000 ha of privately owned land could be planted in block plantations over a 15-year period — 78,000 ha in Ontario, 78,000 ha in Quebec and 39,000 ha in the Atlantic provinces. The annual target planting would be 15,000 ha per year, with a ramp-up to the annual planting target by 2005. This action requires that landowners commit to removing blocks of their farm land from their current agricultural uses, if any, and converting them to tree plantations. Block plantations would vary in size depending on individual farm size and landowner interest. The 78,000 ha target for Ontario is about 50% higher than the land planted under the *Ontario Woodlands Improvement Act* which was in force for two decades from the mid-1960s to the mid-1980s. For the purpose of developing this option, specific tree species and their distribution were selected. Final species composition will be determined based on expectations as to the best possible uses of the plantation in the future, whether for environmental purposes, forest products or energy.

Table 3.2.13
Action Costs and GHG Impacts of Eastern Canadian Block Plantations

	Estimate	Assumptions
Planting program		
· planting period	15 years	-program starts in 2000, with planting beginning in 2001;
· annual planting target	15,000 ha/yr	-5-year ramp-up to annual planting target by 2005
· total planting	195,000 ha	
Incremental CO_2 sequestration		
· 2010	0.22 Mt CO_2	-includes both above- and below-ground biomass and soil carbon;
· 2000-2050, annual average	1.37 Mt CO_2 /yr	-emissions from fossil fuels used in planting are excluded from the estimates; net carbon sequestration prior to the plantations is assumed to be zero
Costs		
· average planting cost (1997$)	$ 1,500/ha	-includes cost of site preparation, seedlings, follow-up care and labour
· average annual opportunity cost (1997$)	$ 10/ha/yr	
Cost calculations		
· NPV of planting costs (1997$)	$ 147.2 million	-uses a 10% discount rate
· NPV of opportunity costs (1997$)	$ 9.8 million	-uses a 10% discount rate; payments made for 25 years
· cost effectiveness 1997$/tonne		
-2008 to 2012	$ 144.9/t CO_2	-using total non-discounted carbon sequestration (2008-2012)
-2000 to 2050	$ 2.3/t CO_2	-using total non-discounted carbon sequestration (2000-2050)

Note that the level of sequestration in the first commitment period is highly dependent on the species chosen and on the planting schedule (e.g. a delay in planting to 2005 reduces sequestration in the first period by over 50%). Irrespective of when planting starts, carbon sequestration would continue to occur after 2050, depending on the species used, so that the cost per tonne of CO_2 sequestered when considered over a longer period than 2000-2050 would be lower than shown in the above Table. Planting costs for will vary widely from site to site and are uncertain. Soil carbon represents about 7% of the total carbon sequestered during the first commitment period and about 15% over 2000-2050.

The estimates of sequestration are based on growth curves which reflect experience with plantations in Atlantic Canada. Thus these growth curves show faster growth than is usual for unmanaged forests, at least in the early decades of tree life. Using different growth curves can result in substantially different results, especially in the first few decades after growth. For example, we explored the sensitivity of the results to using a set of lower growth curves based on non-plantation forests in Ontario. With these lower curves, sequestration in 2010 falls to 0.08 Mt CO_2 while sequestration over 2000-2050 averages 1.70 Mt CO_2 per year. Accordingly, cost effectiveness in 2008-2012 was 1997$410/t CO_2 and $1.9/t CO_2 over 2000-2050.

Given the great uncertainty about opportunity costs, we also assessed the impact of an annual opportunity cost of $50/ha/yr. Using this opportunity cost results in a cost effectiveness for 2008-2012 of 1997$181/t CO_2, up from $145/t CO_2 when the opportunity cost is $10/ha/yr.

While the same species is used for each region, cost effectiveness varies across the regions because of differences in the distribution of the species in terms of areas planted. A breakdown of the estimates by provinces in Atlantic Canada was not done but most of the lands targeted are located in New Brunswick and Nova Scotia.

Table 3.2.14
Regional Implications of Eastern Block Plantations

Region	Planting Target ha/yr	Mt CO_2 Sequestered 2010	Mt CO_2 Sequestered per year, 2000-2050	NPV of Planting and Opportunity Costs 1997$ millions	Cost Effectiveness	
					1997$/t CO_2 2008-2012	1997$/t CO_2 2000-2050
Ontario	6,000	0.11	0.56	62.8	120.0	2.2
Quebec	6,000	0.08	0.55	62.8	159.7	2.3
Atlantic	3,000	0.03	0.26	31.4	188.4	2.4
TOTAL	**15,000**	**0.22**	**1.37**	**157.0**	**144.9**	**2.3**

3.2.8 Further Assessment of Afforestation Actions

Competitiveness, Economic and Social Implications

- Sale of wood from block plantation actions will affect future timber supply. This may result in a reduction in future harvests on existing forested areas, or it could be used to develop new manufacturing facilities.
- Afforestation will present economic development, employment and diversification opportunities for rural communities in the form of tree planting and maintenance, and increases in nursery production. In the future, additional wood supplies for products or energy may also contribute.
- Nursery capacity for the production of the additional seedlings varies by region. Existing capacity is thought to be sufficient in B.C. In the Prairie provinces, existing capacity is considered sufficient to handle planting of roughly 33,000 ha/yr. This means that existing capacity is just sufficient for the proposed level of planting of the two Prairie actions combined. Overall, seedling supply is not likely to be a limiting factor given the five year ramp-up period.
- This action may have impacts on the agricultural sector if production of agricultural products are reduced, depending on the type of activity that occurred on the land diverted to shelterbelts or block plantations. The net effect on landowners, the agri-food industry and consumers will depend on the changes in prices paid for farmers' products, and policies in the agricultural sector. The net effects are expected to be minimal due to the relatively low productivity and use of most of the agricultural lands planted.

Environmental and Health Impacts of Planting Actions

Positive Environmental Effects

The afforestation of marginal agricultural land can result in a range of environmental and land management benefits in addition to direct carbon sequestration benefits. These benefits include: improving overall soil and water quality; rehabilitating previously degraded lands; restoring degraded or fragmented forests; providing habitat for wildlife and increased biodiversity; providing rural diversification and aesthetic landscape benefits; and increasing the availability of renewable biofuels (as a substitute for fossil fuels and reduced CO_2 emissions) and long-lived forest products (as a store of CO_2 and substitute for other energy intensive building products).

The afforestation of marginal agricultural land results in lower pesticide and chemical use, and reduced leaching into groundwater and aquatic ecosystems compared to intensive agriculture. Afforestation can also reduce soil erosion and improve soil quality through increased stabilization of soils and regulation of water run-off, and it can rehabilitate lands degraded through previous land-use practices. Research is continuing on the potential use of salt-tolerant tree species to rehabilitate saline areas, which occur mostly in the Prairie Provinces.

Afforestation can contribute directly to promoting biodiversity and the provision of wildlife habitat through the replacement of land used for agricultural purposes with a more complex vegetation structure and forest ecosystem. The design and structure of afforestation planting can greatly influence the level of enhanced biodiversity benefits, and be complementary to other regional conservation objectives and adjacent ecosystems. Afforestation could also provide protection of headwaters, recharge areas and riparian areas. Protection of water quality and quantity will be especially important if climate change causes an increased incidence of drought in some parts of the country.

Increased afforestation will promote additional landscape, aesthetic and recreation benefits through an increase in forest cover and diversification of rural activities and opportunities. Afforestation based on agroforestry and shelterbelt systems can increase soil and cropland productivity, and provide additional agricultural benefits such as the provision of shade and shelter for livestock.

The environmental benefits of increased afforestation extend beyond the direct CO_2 sequestration of standing trees, and include the potential use of these trees as a renewable biomass fuel and substitute for fossil fuels. Offsetting the end use of fossil fuel reduces cumulative concentrations of air emission pollutants, including: carbon dioxide (CO_2) and nitrogen oxide (NO_X), along with smaller amounts of methane (CH_4), carbon monoxide (CO) and volatile organic compounds (VOCs).

The harvesting and production of solid wood products from afforestation areas acts as a long-term store of CO_2, and may be less environmentally damaging than other building materials and substitutes (e.g. concrete and steel) on a product life cycle basis. The life cycle benefits and costs of using forest products compared to other building products is an area of continuing research.

Adverse Environmental Effects

Afforestation programs will increase the use of pesticides and fertilizers when taking place on lands that were not previously in intensive use. As well, the overall soil and water quality improvements of an increase in afforestation may be partly offset in some cases by increased water and nutrient deficits where intensive short rotation species are used. These potentially adverse effects reflect the high water and nutrient demands of short rotation species, but can be mitigated through careful planning and use of sustainable planting practices (e.g. planting only on lands with the biophysical capability to support short rotation species). There is also some uncertainty on the net changes to soil carbon in the first few years following afforestation, although soil carbon increases over the life of the rotation.

Increased afforestation will result in higher standing biomass, and the potential risk of increased fire and spread of forest diseases and pests compared to some pre-existing land uses. These potentially adverse effects can be mitigated through

the use of fire protection measures and other planting controls designed to minimize the risk of pests and diseases, such as the use of appropriate tree species and pest control agents.

Non-forested areas can be quite complex and rich in terms of biodiversity and habitat (if not used intensively for agricultural purposes) and afforestation will replace this with new types and levels of biodiversity and habitat. Where plantations rely on one or a few species, especially if they are not indigenous to the location of the plantation, habitat diversity and biodiversity could be adversely affected.

Information Gaps

The overall soil and water quality changes resulting from afforestation on marginal agricultural land are generally well documented in the scientific literature, and quantified at a local level in many cases. Some key information gaps, or areas requiring further research, include: research and development on suitable salt-tolerant tree species; soil and below-ground carbon changes in the first few years following afforestation; potential off-site impacts of chemical and pesticide use in afforestation projects on aquatic and terrestrial ecosystems; the long-term effect on water and nutrient budgets from increased afforestation (particularly for short rotation species); and the life-cycle benefits and costs of using forest products compared to other building products.

Summary

The afforestation of marginal agricultural land for carbon sequestration can result in important land management benefits, and in some cases adverse impacts, in addition to direct CO_2 sequestration benefits. The distribution of positive and negative impacts will be site specific. The benefits include improvements in overall soil and water quality; rehabilitation of previously degraded lands; providing habitat for wildlife and increased biodiversity; and increased rural diversification and aesthetic landscape benefits. Other CO_2-related benefits include increasing the production of renewable biofuels (as a substitute for fossil fuels and reduced CO_2 and other emissions) and long-lived forest products as a store of CO_2. The positive and negative environmental effect will be more extensive in the Prairie provinces, where the largest share of the afforestation will occur.

Extent of Use of Planting Actions in Other Countries

- Other countries, such as the United States, are known to be exploring the potential for using domestic afforestation projects to help meet their Kyoto Protocol target. In countries such as New Zealand and Australia, new afforestation has occurred in the expectation of obtaining carbon credits. Domestic and foreign private companies have been involved in the efforts.
- A number of countries will benefit from carbon sequestration as a result of significant afforestation efforts (since 1990) that pre-date the Kyoto Protocol. Among these countries are New Zealand, Australia, Argentina and Ireland. Some countries provide significant direct government support for afforestation (Argentina, Ireland) while others have provided indirect support through regulatory changes which encourage investment in forest plantations (New Zealand). In each case, the motivation of the government has been primarily to increase development of the domestic forest industry rather than carbon sequestration.
- Some countries, such as the United States, have established afforestation programs designed to achieve conservation objectives on agricultural land and remove marginal agricultural land from production. In the United States, a variety of programs provide partial funding for tree planting for conservation purposes.

Further Analytical/Study Needs

- The analysis of the actions varied in terms of accounting for carbon. Soil carbon sequestration due to the Prairie and B.C. actions was not assessed. The analysis for this Prairie block action assumed that net annual carbon sequestration prior to block plantation planting was modest. This is assumed to be lost when plantations are developed, resulting in a slight reduction in net incremental carbon sequestered due to the action. The magnitude of this effect is very uncertain. For all of the other actions, the impact of afforestation on pre-existing levels of carbon sequestration were not estimated. Accounting for pre-afforestation carbon sequestration rates may raise or lower the net sequestration from the actions but there is inconclusive information on this topic, and it is also not clear whether this will be a required part of the accounting procedures for obtaining credit.
- Only tree species were included in the actions, and early growth rates for all species are very uncertain. The use of shrubs or native tall grasses are other good possibilities that should be examined for cost effectiveness, especially in relation to shelterbelts and plantations established as a feedstock for bioenergy, and for environmental purposes. Results of the Prairie Farm Rehabilitation Administration's program show that a higher level of sequestration can indeed be obtained with a combination of trees and shrubs.
- Only direct planting and maintenance costs were estimated. Costs and potential benefits which have not been accounted for include: forest protection costs; afforestation program costs; the net revenue of harvesting and use of mature stands; carbon monitoring, measurement and verification costs; and the potential value of carbon credits.
- The level of incentives needed to achieve the targeted level of planting is very uncertain and will have to be investigated more thoroughly as program development occurs — it is the level of incentives that is offered that will have the most impact on the total land afforested. In particular, a relatively ad hoc assumption was used in the analysis of the actions to indicate the scale of the opportunity costs of afforestation.
- The use of public land for afforestation was not addressed in the analysis. In certain provinces, such as B.C. and Alberta, large areas of public land are leased for range and this might be suitable for afforestation.
- Further study is needed of the implications of the various end uses as well as the market opportunities associated with afforestation.
- A useful way to gather more in-depth information would be regionally targeted surveys of rural landowners to determine their level of interest, motivation, land availability and its current condition, and the level and structure of incentives that would be required for their participation in afforestation.

Relationship of Planting Actions to Each Other and to Other Actions

- The afforestation actions complement each another. The two Prairie actions are qualitatively different — the shelterbelt action is expected to be adopted by a larger number of farmers but with much smaller planting areas per farm then will be the case with plantations. As well, the shelterbelt action focuses on soils that are of medium and poor quality for trees while the block plantation action focuses on good soil areas.
- Afforestation could be considered as a possible source of future energy supplies, and in this respect this action may complement fuel switching actions in the forest sector and in other sectors. This possibility is heavily dependent on relative fuel prices and on government policies to encourage the use of bioenergy.

3.3 Currently In Protocol with Highly Uncertain Definition – Reforestation

3.3.1 Analytical Issues and "Business as Usual" Estimates

Uncertain Negotiating Outcomes

The changes in carbon stocks between 2008 and 2012 on areas reforested since 1990 may be used to offset Canada's target in the commitment period. However, the definition of reforestation under the Kyoto Protocol is still to be negotiated internationally. There are two distinctly different interpretations that are critical to any forecasts of estimates of future potential. Many countries think that reforestation should be defined similar to the definition in the IPCC GHG emission inventory guidelines: "planting of forests on lands which have, historically, previously contained forests but which have been converted to some other use." The United Nations Food and Agriculture Organization's definition is

"the establishment of a tree crop on forest land." Canada has suggested as a working definition "a land-use practice that, through the re-establishment of a stand of trees, forms a forest."

At issue in these contrasting definitions is whether the re-establishment of trees after harvesting (i.e. regeneration) is included under the Protocol as reforestation or not. If a definition similar to the IPCC definition is accepted internationally, then reforestation will in fact be "re-afforestation," or afforestation in the sense that it is presented in Section 3.2. Clearly, most areas in Canada that are currently without tree cover and are available for tree planting (e.g. marginal farmlands) were at one time "historically" forested.

If the narrow, non-forestry related IPCC definition is adopted, then there are essentially no "forestry" activities under Article 3.3. of the Protocol, which refers to direct human-induced "land-use change and forestry activities of afforestation, reforestation and deforestation." By limiting the definition of reforestation to a solely land-use change definition, those Parties for whom forests require on average 100 years to reach maturity receive credit for a very small sink in the commitment period. At the same time, including deforestation occurring in the commitment period, without balancing this against the growth in the rest of the managed forest, can, as shown in the recent SBSTA workshop in Rome, result in perverse consequences. More specifically, a Party may be required to report an increase in emissions (i.e. from deforestation) when overall, as a result of good forest management on the rest of the forest, the forest has continued to act as a sink and credit should be given. Under the FAO or Canadian working definition for reforestation, and assuming that credits are only obtained on the Kyoto Forest, a potential credit could be obtained even when the total volume of carbon stocks on the managed forest is stable or declining.

Many Sinks and Forest Sector Table members hold strong and divergent views on which definition is the 'right' definition, as well as which one is the most likely to be agreed to internationally. Some have argued that it is inconceivable that reforestation, defined as regeneration, would be agreed to, without adding in harvesting as the balancing source to the reforestation sink. The problem is that the "balance" to harvesting is not the growth on areas reforested since 1990, but is the total annual growth of the managed forest. Under sustainable forest management, the volume harvested equals the growth of the forest, given certain assumptions about age class distributions and other factors.

Another argument that has been put forward against defining reforestation as regeneration after harvest is that currently the IPCC guidelines consider the use of biomass for energy to be CO_2 neutral, because the biomass is assumed to come from a sustainable forest management regime. Therefore, to obtain credit for reforestation/regeneration, and to have no responsibility for a debit when using the biomass as fuel (when the reason that there is no debit is that it is assumed to be a sustained and renewable resource) seems to be counter-intuitive. Clearly, Canada is only one country of many who will be party to negotiating the definitions, and any forecast of the outcome of negotiations is speculation at this point.

The BAU estimates of CO_2 sequestration from reforestation are summarized in Table 3.3.1 on the following page. These estimates do not reflect the impact of "incremental" or "enhanced" regeneration, but are estimates of the net CO_2 benefits under alternative definitions under the Protocol that could be used to contribute towards Canada's commitment without further investment or policy changes. Because of the uncertainty over definitions, the net CO_2 sequestered is presented under the two divergent definitions. If reforestation is defined according to the IPCC definition then the BAU estimate for reforestation is equal to the CO_2 sequestration from BAU levels of planting on agricultural land (assumed for now to be negligible).

If reforestation is defined as regeneration after harvest (i.e. the FAO definition), then BAU estimates obtained by the Tables for 2010 are in the -2 to 13 Mt/y range depending upon carbon stock components. Which components of carbon stocks will be counted is critical, since there are indications that changes in below-ground and soil carbon cause areas to be a net source for 10 to 20 years after harvest, even if the slash and litter from harvesting is excluded from the calculations. Preliminary analysis, done for Eastern Canada, indicates that if post-harvest litter and slash are included, Eastern Canada would be a much larger source of about -18 Mt CO_2 (as opposed to –4 Mt if slash is excluded). This would be particularly the case for naturally regenerating areas, and not so much for replanted areas. Because harvesting is excluded from the Protocol, there have been suggestions that the slash and litter resulting from harvest should not be considered part of the carbon stocks on the site during reforestation. There are practical difficulties with this notion, particularly related to measurement and monitoring.

Table 3.3.1
BAU Estimates of Reforestation Under Two Alternative Definitions, Mt CO_2 / yr

Definition of Reforestation	Carbon Stock	2010 Mt CO_2/yr	2020 Mt CO_2/yr	Assumptions
FAO definition: regeneration after harvest				
Western Canada	a. Above-ground biomass	2	8	Based on harvest forecast to 2020; only sequestration due to reforestation since 1990 is included
	b. Above- and below-ground biomass, and soil	2	10	
Eastern Canada	a. Above-ground biomass	11	35	Based on harvest forecast to 2020; only sequestration due to reforestation since 1990 is included
	b. Above- and below-ground biomass, and soil	-4	27	
Total Canada	a. Above-ground biomass	13	42	Based on harvest forecast to 2020; only sequestration due to reforestation since 1990 is included
	b. Above- and below-ground biomass, and soil	-2	37	
IPCC definition: re-afforestation				
Total Canada	All forest carbon stocks	0	0	Considered as afforestation
Harvesting	Above-ground biomass only	-210	-210	1996 harvest volumes of 183 million m³ converted to CO_2 (assuming emissions in same year as harvest)

In Table 3.3.1 there is a large discrepancy between the estimates for Eastern and Western Canada under the FAO definition, reflecting differences in the methodologies and assumptions used to derive the estimates. Further refinement of these numbers clearly is needed. The above-ground BAU estimates are reasonably consistent with those reported in the Forest Sector Table and Sinks Table Foundation Papers. Note also that these BAU estimates include both natural regeneration after harvest and planting and seeding. Approximately 50% of harvested areas are regenerated naturally after harvest. Although it is possible that this type of definition of reforestation would exclude natural regeneration, the industry generally "assists" regeneration by post-harvest treatments such as scarification. In addition, there is an increasing use of specific harvest techniques such as shelterwood systems to promote natural regeneration. Also shown for reference is harvest volume converted to CO_2-equivalent emissions. Clearly, this would add a huge debit to Canada's target.

International agreement may not be reached until CoP6, or later, on the definition of reforestation. In addition, it is not yet known which carbon stock components will be counted for the purposes of determining compliance with the Protocol. It is clear that carbon sequestration from above ground tree biomass is included, but there is some uncertainty as to whether carbon sequestration in soils and below-ground biomass will be included. Future negotiations will also develop guidelines, rules and procedures for measurement, monitoring and verification of sequestration. The costs of these activities will vary according to the requirements, the type of reforestation and reforestation policies. These costs were not assessed by the Forest Sector and Sinks Tables.

The following discussion and options refer only to the FAO definition of reforestation, (i.e. "the establishment of a tree crop on forest land"). Under the IPCC definition, virtually all of the planting programs described in Section 3.2 on afforestation would be considered reforestation, and none of the activities in this section would be eligible for credit under the Kyoto Protocol.

Accounting Issues

There are significant accounting and measurement issues associated with reforestation if defined as regeneration after harvest. One of these is how to determine carbon stock changes due to regeneration if harvesting methods other than clear cutting are used. In the case of clearcuts, a definite area is cleared of all standing above-ground woody biomass (i.e. trees), and the change in carbon stocks over time is based on the growth of planted or naturally regenerated young trees (the monitoring and measurement of woody debris and below-ground and soil biomass is not as straightforward). However, if an area is harvested using a partial cutting method (i.e. not all of the trees are removed), then it is not straight forward to measure the change in stocks during the commitment period. The main problem is that it is difficult to specify what portion of any growth on a site that has been partially cut is due to anthropogenic activity and what portion is "natural." Excluding partially cut sites from the reforestation definition is not a solution, as it would provide an incentive to favour clear cutting over other harvesting methods. Canada currently uses partial cutting on approximately 10% of areas harvested, although the proportion is growing. Many other countries, such as the U.S. harvest most areas using partial cutting. Given the wide range of harvesting methods in use around the world, this issue will need to be resolved for both political and environmental reasons, should reforestation be defined as regeneration after harvest.

Another question (also valid for afforested areas) is how to account for the change in carbon stocks when an area within the Kyoto Forest (i.e. regenerated since 1990) is then harvested, given that harvesting is not currently included in the Protocol.

Policy Environment

Canada's forests are predominantly publicly owned. Approximately 71% is owned by the provincial governments and 23% by the federal and territorial governments. Harvesting on this public land base is regulated through various tenure arrangements with private companies. Companies are regulated in terms of amounts and areas harvested per year as well as the ongoing management and regeneration of sites after harvesting. Forests are managed for multiple values, and provinces and companies are working towards improved sustainable forest management practices. Harvesting on private lands is not regulated, although some provinces are starting to introduce incentives to improve forest management on private lands. In addition, in some provinces where companies operate on both public and private lands, the proper management of their private lands is linked to their tenure rights on public lands.

The implications of the ownership and management regimes in Canada is that there is currently little flexibility to increase carbon storage through changes in reforestation practices. Companies are bound by codes of practice and silvicultural prescriptions to regenerate forests in particular ways. Two elements of regeneration strategies that have significant impact on sequestration potential are species selection and spacing or density management. These could be investigated to determine the impact of modifications to enhance carbon storage. However any changes would need to be balanced with the myriad of other considerations and values that are taken into consideration in forest management.

Choice of Species

Assuming that reforestation includes regeneration after harvest, a key determinant of the total sequestration that will occur is the choice of species. Species traditionally used for forestry, and for which seedling stock is relatively abundant, have relatively low sequestration rates in the Canadian climate. Faster growing species, such as hybrid poplar, can reach peak annual carbon sequestration rates in 10 to 25 years. The fastest growing tree and shrub species can take as little as 5 to 8 years. Provincial agencies generally require that areas are regenerated to the same species as was harvested, or in some cases, stand conversion to another more suitable or more commercially viable species is carried out.

Although there is still uncertainty as to how reforestation credits will be measured, its seems likely that the total carbon credit available on a given site will be limited to the maximum (rather than the total) volume of carbon that accumulates on that site (i.e. over one rotation). Using fast-growing species, therefore, while having potential to increase carbon credits during the first commitment period, may not result in a net long-term benefit.

Whatever the species chosen, a difficulty in estimating the sequestration impact of reforestation actions is the lack of good information on tree growth curves, especially in the first two decades after planting which is the key period for determining the impact in the first commitment period. This introduces an unknown degree of uncertainty into the estimates of sequestration due to the actions.

Impact on Environment

Although negotiations are not yet completed on the RAD and definitions are not yet determined, there is an important environmental aspect of reforestation that should be noted. If reforestation is defined as regeneration after harvest, the net impact on the atmosphere is that more industrial carbon emissions will be emitted, since the amount of CO_2 sequestration from reforestation will be offset from Canada's target, and industrial emissions will not need to be reduced by as much. Under this definition, Canada essentially gets a "windfall gain" because it has been harvesting and regenerating approximately 1 million hectares per year since 1990 and would, therefore, would get this credit without necessarily increasing the amount of carbon stored in its forest over the long-term. This definition of reforestation allows countries in essence to defer taking actions that will have an impact on CO_2 concentrations in the atmosphere.

There are actions that can increase the carbon sequestered on regenerating sites, (i.e. incremental increases over and above that which would normally carried out). These actions may have some beneficial impacts on the atmosphere, although their impact in the long run is not clear and will depend upon a variety of factors, including species and rotation age. However, the potential incremental amount from these actions is small compared to the total carbon sequestered through reforestation.

From the point of view of Canada, however, reforestation can provide a significant contribution to meeting Canada's target in the first commitment period under the National Implementation Strategy, under a definition that includes regeneration after harvest.

There is also some concern that a definition of reforestation that includes regeneration after harvest could have the perverse effect of increasing the rate of harvest (for which there is no debit under the Kyoto Protocol at present) in order to obtain credit from reforestation. This is unlikely to occur in countries like Canada where forests are predominantly publicly owned and managed, and where significant codes of practice and regulations are in place. This concern is most relevant for private lands that are not regulated or in countries that do not have or enforce adequate regulations to ensure sustainable forest management practices.

3.3.2 Modification of Reforestation Methods to Increase Carbon Sequestration After Harvest

Note that the discussion here assumes that negotiations result in a definition of reforestation similar to the one used by the FAO and proposed by Canada. The actions discussed are those which will potentially increase carbon sequestration on areas regenerating after harvest since 1990, as well as on areas to be harvested in the future, relative to the BAU case. Because of the considerable definitional uncertainties, any actions or policies to facilitate actions must be considered carefully before implementation. Those actions that do not adversely affect other objectives, or that are cost-effective and complementary to other objectives, are obvious contenders. Actions aimed at maximizing on-site carbon sequestration and storage over the long-term are not the same as, and in some cases may conflict with, actions aimed at maximizing sustained yield of timber. Multiple objectives will need to be considered in determining the best strategies to adopt.

Use of Genetically Enhanced Trees

One possibility is the use of genetics and tree breeding programs to develop faster-growing trees. The main driving factor for the development of faster-growing and disease-resistant trees has been and will continue to be wood supply for the forest industry. The first generation seed orchards began to yield operational quantities of seed in the early 1990s. The volume increases of 10 to 30% are expected to result, and further increases should result as tree breeding programs continue. By 2005, about half of all planting is expected to be using faster-growing trees. Efforts to accelerate tree-breeding programs, and development and use of faster-growing trees, could contribute to meeting Canada's Kyoto

target. The cost of this needs to be investigated but a rough idea of the possible carbon impact can be derived using the same assumptions used to derive the BAU estimates. The effect in the first commitment period of a 15% increase in tree growth on all areas planted/seeded since 2000 is an increase in the annual sink of about 0.5 Mt CO_2 in the first commitment period.

Density Management

There has been considerable research carried out in recent years on the impacts of density management, including juvenile spacing and pre-commercial thinning. Juvenile spacing or pre-commercial thinning is the deliberate removal of excess stems from overstocked stands of young trees (usually 10 to 14 years old) in order to reduce competition for space, light, water and nutrients. A number of provinces have produced managed stand yield tables for commercial tree species for various planting densities or spacing regimes. While current guidelines and research is aimed at maximizing commercial volumes at harvest, there is some research that indicates significant biomass gains can result from modifications in planting or spacing regimes.

Species Choice

As noted above, species selection can have a significant impact on carbon sequestration. In particular, some species that are faster growing may be shorter lived, but reach higher rates of CO_2 sequestration earlier than others (e.g. poplar). Most provincial agencies have requirements for regeneration after harvest that relate to species selection. Generally, the same species must be regenerated as was harvested unless stand conversion is desired. Any species changes to increase CO_2 sequestration would need to be considered in light of other objectives such as final products, biodiversity, aesthetics, etc.

Increased Use of Planting Instead of Natural Regeneration and Seeding

After harvesting, forests in Canada are regenerated by either planting (45%), seeding (5%) or natural regeneration (50%). Planted trees generally reach maturity 10 to 13 years earlier than naturally regenerated stands. In part, this is because trees that are planted are already several years old but, in addition, some form of chemical or mechanical site treatment reduces weed competition and allows young trees to establish themselves earlier. Planting also offers the opportunity to use genetically enhanced seedlings, or to change species to one more suited to the site.

However, most provinces have numerous environmental objectives in addition to those related to climate change, and many of these are consistent with a high percentage of naturally regenerated areas. It is also the most cost-effective method of regeneration in most areas where it is carried out.

Expected Action Cost and GHG Impact

Little analysis has been carried out on the potential GHG impacts and related costs of these types of activities. The bulk of the GHG reduction benefit from reforestation will be attained under the business-as-usual scenario if the definition of reforestation includes regeneration after harvest. Obviously, none of these actions would be carried out (at least for the purposes of increasing sequestration to meet Canada's target) if the Protocol does not allow credit for reforestation as defined this way.

Barriers to Implementation

- Negotiation outcomes, in particular the definition of reforestation, will determine whether the net carbon sequestration from these actions counts towards Canada's target. Which components of carbon stocks will be counted is also critical.
- Other values in the forest, including biodiversity, wildlife, aesthetics, stream quality, etc., may be adversely affected by some of these actions. Sustainable forest management practices strive to achieve a balance among many objectives.

- Changes to species mix must take into consideration potential climate change impacts on growth rates, and insects and disease factors.
- Costs of planting are higher than natural regeneration or seeding. In addition, some sites are inappropriate for planting due to location, accessibility or site conditions. Other activities, such as juvenile spacing, are also rarely practiced due to cost.
- Who owns carbon credits on public lands is an issue that will need to be resolved. For example, if a company has a forest management agreement with the province, and invests its own money to increase carbon sequestration, they need to be assured of obtaining the C credit. A related question is who "owns" the risk of losses and carbon debits. In addition, issues related to security of long-term tenure rights for forest companies are relevant.
- On private lands, woodlot owners can only write off the costs of planting if it occurs in the same year as the harvest, which is often difficult and, therefore, a disincentive to planting. In general, tax treatment of woodlots is unfavourable compared to agriculture and grazing. Farmers can carry forward tax losses while woodlot owners cannot.

Policy Requirements

- Since most harvesting and reforestation is carried out on public lands, the provincial governments will be the main sources for policy changes
- Incorporating GHG sequestration objectives into forest management planning objectives is possible, but only taking into account the balance of other values and objectives on public lands.
- If companies can obtain carbon credits for the GHG sequestered from actions to increase reforestation, then this may provide sufficient incentive to change practices.
- Alternatively, provincial governments could offset private company costs for practices that increase GHG sequestration.
- Provincial regulations to control over-harvesting on private lands (to prevent owners from harvesting in order to obtain credit for reforestation) may be required.
- Provincial regulations mandate prompt regeneration of harvested areas, yet there is still 3 million ha of area that is not sufficiently restocked (NSR). This area is declining over time as backlog NSR is planted, but new NSR is added when areas do not regenerate in a reasonable amount of time. In order to ensure prompt regeneration of sites, more consideration of regeneration systems including modification of harvesting techniques is needed.

Regional and Intra-Sectoral Implications

- The area harvested per year in Canada is approximately 1 million ha. Quebec, Ontario and B.C. represent approximately 75% of this. Harvest volumes are highest in B.C., followed by Quebec and Ontario. B.C. has the highest productivity (annual growth rates) particularly on the coast. Estimates show higher carbon sequestration in the eastern provinces than in the west, but this is largely a function of different methodologies and assumptions used by the consultants.
- Any increases in GHG sequestration due to changes in reforestation techniques may also increase merchantable wood volumes, which will increase wood supply for the forest products industry. Some changes may result in a shift from sawlogs to pulplogs or vice versa. Changes in species composition will impact final products.

Competitiveness, Economic and Social Implications

- Increasing costs of reforestation, if borne by forest companies, would increase delivered wood costs and negatively impact competitiveness.
- Modification of reforestation practices could generate some increases in seasonal employment for tree planters and forest management contractors.
- Significant increases in growth due to changes in regeneration practices could yield long-term benefits in terms of increased harvesting and related forest product production.

Environmental and Health Impacts

Modifying reforestation methods to focus on increased CO_2 sequestration is likely to result in a range of environmental costs and trade-offs with other forest management objectives. These potential trade offs include biodiversity conservation and ecosystem management objectives (e.g. provision of stand structural diversity and habitat); aesthetic landscape and recreation planning; stream and water quality considerations; and long-term regeneration objectives (e.g. use of native tree species to minimize biological risks and diseases). The precise nature and extent of these types of trade offs is uncertain and is an important information gap.

Extent of Use of Same or Similar Actions/Measures in Other Countries

- Many countries oppose a definition of reforestation that includes regeneration after harvest. It is unknown at this time if any countries are developing plans to increase reforestation growth to respond to the Protocol.

Further Analytical/Study Needs

- Further work on ownership issues around carbon credits is needed.
- Improved growth and yield information for second growth stands is needed. In particular, the C sequestered in young stands (first 30 years of growth) is poorly understood, and the difference in growth between naturally regenerated versus planted forests, are poorly understood.
- The carbon sequestration potential and the related cost per tonne from the four sub-actions needs to be determined for all carbon pools. While a fair amount of information is known about the impact of these actions on above-ground biomass (predominantly merchantable tree volumes) in specific regions and for specific species, the impact on a broad national scale is not known. In addition, the impact on soil carbon — as well as below-ground biomass and dead organic matter carbon pools — needs to be analyzed, which will likely involve collection of basic site-level data.

Relationship to Other Actions/Measures

- This action is related to afforestation and to the managed forest actions.

Stakeholder Views

Consideration of modifications to reforestation methods to increase carbon sequestration may increase the planning and resource demands on public forest managers, adding to considerations of multiple objectives and other legal and policy requirements (e.g. codes of forest practice). There may also be concerns from community groups and stakeholders with direct interest in the management of public forests for other values (e.g. recreation and hunting associations).

The appropriateness of defining reforestation as regeneration after harvest in the Kyoto Protocol raises concerns. In particular, the views of environmental non-governmental organizations can be summed up as follows:

1. The proposed definition undermines the Convention, for the following reasons:

    - It provides for a large carbon credit without there necessarily being any increase in the amount of carbon stored in the forest over the long-term. In fact, in certain cases — such as the conversion of high-volume old growth stands — there would be a significant <u>reduction</u> in the total volume of carbon stored on the site, but the "reforestation" credit would still apply.
    - It allows for the double counting of carbon credits related to fossil fuel substitution.

1. The proposed definition would create potentially perverse incentives running contrary to sustainable forest management:

   - By providing a credit that increases as the harvested area increases, it creates an incentive to increase harvesting levels, having a potentially negative impact on a range of environmental and social values. This is of particular concern on private lands.
   - There is, as yet, no clear understanding of how reforestation credits would apply on lands that have been harvested by selection cutting methods. However, in general forestry parlance these areas are not considered to be "reforested." If they are excluded from eligibility for Kyoto credits then there would be a substantial incentive to avoid using these methods in order to obtain the "credit for clearcuts."

3.4 Included in Protocol with Moderately Uncertain Definition - Deforestation

Deforestation is one of the three activities (reforestation, afforestation and deforestation) currently included under Article 3.3 of the Kyoto Protocol. Changes in carbon stock in 2008-2012 resulting from these activities since 1990 will be netted against a country's target. As noted earlier, this creates an imbalance between sinks and sources. Countries will have to account for a potentially large carbon debit per hectare as a result of deforestation (i.e. clearing mature standing timber) but obtain only a very small credit from afforestation and reforestation, because trees will still be very young in the first commitment period as a result of the "since 1990" caveat applied to the RAD activities in the Protocol. Under a managed forest approach (as discussed in section 3.5), this is less of an issue, as there is a more complete accounting of all carbon flows.

Deforestation in the 2008-2012 time period will be counted as a source of CO_2 emissions, and will thus increase Canada's emissions during the commitment period. Deforestation is not included in the 1990 baseline level. As such, deforestation represents a liability, in the sense that emissions from deforestation will increase the overall level of emissions of Canada's business-as-usual scenario above the 1990 baseline level.

The identification of potential policies and actions to reduce current rates of deforestation will be an important part of Canada's overall climate change strategy. Policies to reduce carbon sources from deforestation activities will need to be balanced against other economic and policy objectives, such as regional economic development and employment generation in those regions where deforestation is occurring. However, there is a critical lack of concrete information on the extent and location of deforestation, which precluded the development of specific policy proposals for this Options Paper.

3.4.1 Analytical Issues

Uncertain Negotiating Outcomes

International negotiations on the definition and interpretation of deforestation under the Kyoto Protocol will be an important determinant of what types of deforestation activities will counted as a source of CO_2 emissions. The IPCC guidelines do not provide an explicit definition of deforestation, although they do make reference to the fact that 'conversion of forests is also referred to as deforestation' (IPCC 1996, page 5.6, footnote 7). Consistent with this implied definition, the UNFCCC Secretariat has suggested that deforestation might be defined as "the conversion of forest land to other land-use" (Secretariat UNFCCC 1998a). They have also proposed two alternative refinements of this definition: i) "the direct human-induced change of land-use from forest to other land-use OR the depletion of forest crown cover to less than 10 per cent;" and ii) "the direct human-induced change of land-use from forest to other land-use and the depletion of forest crown cover to less than 10 per cent." This clearly illustrates a key issue related to the definition of a forest (and hence deforestation) — is it based on land-use or land-cover?

International agreement may not be reached until COP6 or later on the definition of deforestation. If the outcome of international negotiations is to define deforestation in terms of the depletion of forest crown cover to below a given level (such as 10%, for example) rather than a change in land use, Canada's emissions from deforestation under the Kyoto

Protocol will likely be greater. This is because there are presently a range of development activities that probably would not be considered a change in land use, such as the establishment of utility lines or forest access roads, but that remove small stands or corridors of trees to below 10% of crown cover.

Canada had suggested to the IPCC for the IPCC Special Report a working definition of deforestation as "a change in land-use that removes a forest" which would include forest conversion for permanent land-use changes, such as agriculture and rangeland activities, as well as development of permanent infrastructure, such as a highways. However, it would exclude areas that did not change the land-use, such as construction of forest management access roads. It is important to point out that harvesting is not considered deforestation, as long as an area regenerates back to forest.

It is not yet determined which carbon stock components will be counted as emissions for the purposes of determining compliance with the Protocol. It is likely that carbon emissions from above-ground biomass following deforestation will be counted, but there is some uncertainty as to whether releases from below-ground biomass and dead organic matter (litter, coarse wood debris and humus) will be included. Which components of carbon stock will be counted will be critical to determining the impact of deforestation as a source of CO_2 emissions. The inclusion of litter, coarse woody debris and 10% of the humus pool, for example, may double predicted estimates of annual CO_2 emissions from deforestation activities (Robinson *et al.* 1999). There is the added question of whether ongoing emissions from areas deforested in 1990 to 2007 will be counted if they occur in the first commitment period — some carbon stocks, such as below ground and soil carbon, will continue to emit CO_2 for many years after deforestation.

Future negotiations will develop guidelines, rules and procedures for measurement, monitoring and verification of biological sources of CO_2 emissions. The cost of policies to monitor changes in deforestation activities will vary according to the requirements and types of deforestation. These costs were not assessed by the Forest Sector and Sinks Issues Tables.

BAU Estimates of Deforestation Activities

Information on the extent of deforestation in Canada is limited, but we do know that it occurs across a range of industry and residential sectors on both public and private forested lands. Major sources of tree removals include agriculture, mining, forestry access roads, and residential and urban development (see Table 3.4.1). This provides a wide range of activities that affect land-use and/or land-cover. It is unlikely that all of these activities or categories would be included in the definition of deforestation to be negotiated under the Kyoto Protocol.

Table 3.4.1
Types of Deforestation Activities

Agriculture and Forestry Activities	Industrial and Urban Development
· land clearing for range · land clearing for agriculture · range encroachment of forest · shelterbelt removal · livestock destruction of riparian forest · construction of forest management access roads and associated infrastructure	· road and rail development · mining and petroleum development (including oil sands development, open pit mining and seismic lines) · flooding of forests for hydroelectric head ponds · utility corridors, rights-of-way · air strips · recreational uses such as ski resorts, golf courses and parking lots

There is limited information available in Canada on the current and recent (since 1990) extent and spatial location of deforestation as this information is not explicitly monitored by federal or provincial agencies. The Sinks and Forest Sector Tables commissioned a study to provide estimates of carbon losses from deforestation from a variety of activities. The estimates, while based on best available information, including a survey of relevant government and industry representatives, are still highly uncertain. Table 3.4.2 summarizes these estimates (Robinson *et al.*, 1999). We

assumed, for the purposes of evaluating the impact of deforestation in the first commitment period, that current deforestation rates and CO_2 emission levels by sector will remain unchanged.

A key requirement for meeting Canada's emission reduction commitments under the Kyoto Protocol will be to further develop measurement and reporting tools to monitor changes in deforestation activities and associated CO_2 emissions. Previous estimates of CO_2 emissions from forest clearing for agriculture and urban development were reported in the Sinks Table and Forest Sector Table Foundation papers, and ranged from between 3 to 19 Mt of CO_2 per year for releases from above-ground biomass and soil carbon. The estimates in Table 3.4.2 narrow the range somewhat, to 9 to 14 Mt of CO_2 per year for above-ground biomass alone.

Table 3.4.2
Deforestation Estimates for Major Sectors
(CO_2 emissions from above-ground biomass only)

Source	Low - High Estimate (hectares per year)	Low - High Estimate (Mt CO_2 per year)	Provinces Where Likely to be Most Significant
Agriculture	10,300 - 30,800	2 - 6	B.C., AB, SK, ON
Forestry	21,600 - 21,600	4	B.C., ON, NB, NS
Urban development	3,600 - 3,600	1	B.C., AB, ON, PQ
Transportation	1,200 - 1,200	0.2	
Recreation	<100 - 500	<0.1	
Mining and petroleum	10,900 - 12,700	1 - 2	AB
Electricity generation	7,000 - 10,100	1	PQ
TOTAL	**54,600 - 80,500**	**9 - 14**	

Table 3.4.3 shows the potential impact on BAU estimates of alternative definitions of deforestation, (i.e. land-use change [excluding forest roads] and a land-use change/land-cover definition). Based on these estimates, it is evident that forest clearing for agriculture, mining and petroleum development and electricity generation are major causes of deforestation under a definition based on a change in land-use. Mining and petroleum deforestation largely arises from oil exploration and infrastructure development in Alberta. Uncertainty in these estimates arise from a lack of information about the range of sizes of new mines. Under a land-use change definition (i.e. excluding forestry roads), Canada's emissions from the three major sources would be between 4 and 9 Mt CO_2 per year.

It should be noted that afforestation programs, discussed in Section 3.2, could be a future potential source of deforestation, if the land does not permanently remain in forest cover. If owners convert to tree cover, but then later decide to return the land to agricultural crops, this would result in a deforestation debit (equal to the carbon credit accrued for the afforested area).

Table 3.4.3
Impact of Alternative Deforestation Definitions

Possible Definition of Deforestation	**Sources by Sector ($Mt\ CO_2$ per year)**	**Total Emissions ($Mt\ CO_2$ per year)**
1) Land-use change only	*Major sources*	
	Agriculture	2 - 6
	Mining and petroleum development	1 – 2
	Electricity generation	1
	Total	**4 - 9**
	Minor sources	
	Urban development	1
	Transportation	0.2
	Recreation	<0.1
	Total	**1**
2) Crown cover/partial forest removals (e.g. forestry roads) only	Forestry	4
3) Land use change and crown cover/partial forest removals	1) + 2) (all sources above)	9 - 14

Forestry

The estimates show that the agricultural and forestry sectors are the two major causes of deforestation and together account for between 6 to 10 Mt CO_2 per year. The estimate for the forest sector of 21,600 ha/year represents approximately 2.2% of the annual area harvested. This estimate is based on a report by CCFM (1997), and summarizes provincial estimates of the amount of non-productive land that is produced annually as a result of "...roads, landing and non-forestry developments that have no timber production objective. These areas also include land where erosion, a rising water table, or other forms of site degradation make a site unsuitable for forestry purposes" (CCFM 1997). Most of the area consists of forest access roads.

The REGEN database, from which these estimates are derived, is updated on a regular basis, and most provinces base their estimates of non-productive land increases on a percentage of area harvested that averages around 4% but ranges from 3 to 7%. The comparable percentage for B.C. (from a different source) is around 5%. Alberta, Quebec, P.E.I, Yukon and N.W.T. do not report creation of non-productive land. If the average of 4% is applied to total harvest area in Canada, the area deforested annually due to infrastructure development could be approximately 40,000 ha per year or almost twice that reported in Table 3.2.2. Both of the estimates exclude secondary roads, landings and skid trails that are generally decommissioned (i.e. rehabilitated and put back into forest).

As noted above, the removal of trees for forest access roads and associated forestry infrastructure may not be considered deforestation if a definition related to land-use change is adopted. A definition that would include forest roads as deforestation would penalize younger countries such as Canada which have less developed infrastructure. And certainly over time, as the industry moves to harvest maturing second-growth stands, this rate of road building should decline. It should also be noted that sustainable forest management practices have, in some cases, led to an increased requirement for roads (e.g. adjacency and "green-up" constraints, coupled with smaller cut block sizes mean that annual harvest areas for a company are spread out over a larger area).

Environmentalists believe that all roads should be considered deforestation, and object to any definition which would distinguish between roads built for the purpose of removing timber (which would not be considered deforestation) and roads built for other purposes (which likely would be considered deforestation). They believe that, from a climate change perspective, this is an arbitrary and illogical distinction to make.

Agriculture

Forest conversion for agricultural activities falls within either definition of deforestation proposed by the UNFCCC Secretariat, and hence, would be a direct source of CO_2 emissions during the first commitment period. Estimates by Robinson *et al.*, (1999) of deforestation in agriculture based on a comparison of land area statistics from the Agricultural Census for 1991 and 1996 are shown in Table 3.4.4. In some provinces, the total area on Census farms has increased greatly over the five-year period. Unfortunately, the data do not allow any inference as to the source of the agricultural land (i.e. whether it was forested or not). Nevertheless, some crude inferences can be made to demonstrate typical orders of magnitude of deforestation activities for agricultural purposes. Excluding those provinces that show a decline, the sum of the increases in total agricultural land area is 1,027 km^2/yr. Assuming only 20% (i.e. half of the 40% of the national land base that is currently forest) of the 1,027 km^2/yr is derived from forests, this would add 205 km^2/yr to the deforestation statistics. Allowing for further uncertainty of ±10% provides upper and lower bounds of 103 and 308 km^2/yr.

Table 3.4.4
Change in the Area of Total Agricultural Land in Canada, 1991-1996

Province	1991 hectares	1996 hectares	Change ha/y	Change km^2/y
British Columbia	2,392,350	2,520,794	25,689	257
Alberta	20,811,074	21,028,729	43,531	435
Saskatchewan	26,865,581	26,568,586	(59,399)	(594)
Manitoba	7,725,017	7,730,941	1,185	12
Ontario	5,451,398	5,603,405	30,401	304
Quebec	3,429,622	3,431,909	457	5
New Brunswick	375,632	376,386	151	2
Nova Scotia	397,033	392,472	(912)	(9)
Prince Edward Island	258,875	264,817	1,188	12
Newfoundland	47,353	43,588	(753)	(8)
TOTAL	**67,753,935**	**67,961,629**	**41,539**	**415**

Source: Statistics Canada (1992) and (1997). Excluding those farms in the 1996 Census that grow Christmas trees only.

A separate study (Tyrchniewicz *et al.*, 1999) was conducted to try to better understand the agriculture/forestry interface and to determine whether there were agricultural or land-use policies in place that might be encouraging deforestation in this sector. An *ad hoc* survey of provincial contacts tended to support the Robinson *et al.*, (1999) study, except for Ontario where the numbers were thought to be too high, and for Saskatchewan where they were thought to be too low. In addition, various Agriculture Table members and provincial Forest Sector and Sinks Table members indicated that the Robinson *et al.*, (1999) numbers may be overestimates, although no better numbers could be offered.

Given the potential significance of agricultural land clearing as a source of deforestation in Canada (accounting for between 20 to 40% of total current emissions from deforestation as presented in Table 3.4.2), and the likelihood that it will be included under the Kyoto Protocol, further analysis into possible actions to reduce clearing of forests for agricultural development should be undertaken.

3.4.2 Policy Environment

It is evident that deforestation occurs in a wide range of sectors, and for many different economic and social objectives, including regional and economic development, employment generation and provision of housing and recreation facilities. Policies targeted at reducing sources of CO_2 emissions from deforestation would need to be balanced against a broad range of activities and policy goals of governments, as well as the interests of stakeholders dependant upon these activities for income and other uses. Furthermore, policies to reduce deforestation will require involvement from all levels of government (e.g. federal, provincial and municipal) given the widespread but scattered occurrence of deforestation on both public and private lands, and the range of policies and regulations that could encourage or restrict deforestation practices. In order to illustrate the complex policy environment and multiplicity of deforestation activities, a range of possible policies are described in Table 3.4.5 to target the major sectors where deforestation is occurring.

Negotiation outcomes, particularly regarding the definition and interpretation of deforestation, will be critical in determining which types of deforestation activities will be counted as a source of CO_2 emissions. Which components of carbon stock releases will be counted, such as above- and below-ground biomass, will also be important. The need to verify and monitor changes in carbon stocks from deforestation activities will require additional scientific tools and measurement systems, depending on the type and extent of deforestation activity. Deforestation which occurs predominantly on private lands such as forest conversion for agriculture, for example, will present additional barriers due to the geographic diversity of land-clearing activities.

If clearing for forestry access roads and infrastructure falls under the definition of deforestation, then various measures could be taken to minimize debits. Various stakeholders suggested options such as increased horse logging or helicopter logging, but the economic and environmental consequences of this type of response would need to be closely examined. In general, it is to be expected that main access road development for the forest sector will decline over time, as more second growth forest is harvested. Specific measures that could be considered for reducing the impact of forest access road building include:

a) reducing the volume of timber harvested (with significant negative impacts on employment and mill viability);
b) reducing the length of roads constructed per unit of timber harvested by increasing the scale of clearcutting to maximize road-building efficiency (with negative impacts to biodiversity, water protection and/or aesthetics);
c) reducing the dependence on logging in unroaded areas by substituting fibre from afforested or other intensively managed areas (with practical problems relating to transportation distance and tenure); and
d) speedy green-up of secondary roads, landings and skid trails (which is presumed in the estimates shown in Table 3.2.2).

Policies to reduce deforestation for agriculture will need to be balanced against other economic and social objectives (e.g. regional economic development and rural employment), due to the importance of agriculture to many rural communities. Also, since most clearing of forests for agriculture and rangeland development likely occurs on private land, policies to reduce deforestation will require the cooperation and involvement of relevant provincial governments and individual land owners. A range of policy options would likely need to be evaluated in order to identify the most cost-effective mix of voluntary and/or non-voluntary measures to reduce deforestation on private land, recognizing the complex range of existing agricultural policies and regulations.

Table 3.4.5
Sample Policies to Reduce Deforestation

Target Source	Types of Policies	Key Stakeholders and/or Public Concerns
Land-use change categories		
Agricultural land clearing	Taxation incentives for forest protection; compensation payments/conservation covenants; forest-clearing planning controls; education and promotion policies.	Reduced returns and lower competitiveness of agricultural sector. May adversely affect some agricultural regions more than others (e.g. western provinces). Monitoring and reporting costs likely to be high.
Mining and petroleum development	Codes of mining practice and regulations to minimize forest clearing; environmental performance bonds; taxation incentives/financial assistance schemes to promote best environmental practice.	Reduced returns and lower competitiveness of mining sector. Regulatory approach likely to increase exploration and mine costs.
Electricity generation	Environmental planning controls/regulations to minimize deforestation at a project level; including off-site requirements (e.g. compensatory planting requirements).	Increased costs of electricity.
Urban/residential development and recreation	Forest-clearing regulations; environmental performance bonds; taxation/financial assistance schemes to reduce forest removals at a project level.	Likely to increase cost of local developments such as housing and recreation (e.g. ski resorts, golf courses). Will involve cooperation and partnerships with provincial and municipal governments. May reduce taxation base of municipal governments through lower investment.
Non-land-use change categories (e.g. partial removal of crown cover)		
Forestry access roads and infrastructure	Codes of forest practice/guidelines to minimize tree removals for forestry infrastructure and accelerate restoration of disturbed sites; off-site programs such as afforestation and use of other intensively managed forests to reduce reliance on unroaded areas for timber supply.	Considered part of normal forestry operations and not deforestation. Likely to restrict ability to access large undeveloped areas across Canada, particularly in British Columbia. Off-site programs unlikely to offset reliance on presently unroaded areas, at least in the medium term.

A study for the Forest Sector and Sinks Tables to investigate whether current land-use or agricultural policies were encouraging deforestation concluded that deforestation for agricultural purposes was limited and tended to be on the decline, and that there was little evidence to suggest that it would increase under current economic and policy conditions. It also concluded that the major factor affecting agricultural clearing was the private landowner's assessment of the relative profitability of land use in forestry versus agriculture, and that the lands which would be most profitable for agricultural use have already been converted to agriculture. Government financial support for agriculture has declined in recent years, reducing incentives for land conversion.

It is important to note that any level of deforestation in the commitment period will increase the challenge in meeting Canada's Kyoto commitment, even if the rate of deforestation is declining over time. This is because CO_2 emissions from deforestation are not included in the 1990 baseline, but the emissions from deforestation in the commitment period

are added to the emissions from fossil fuels to determine compliance with the target, and will increase the mitigation effort required to meet the target. Even a small amount of deforestation can be significant, as the debits are relatively "instantaneous", and cannot easily be offset by credits due to afforestation or reforestation.

A possible perverse effect of deforestation policies may be to accelerate some types of deforestation activities prior to the first commitment period. The potential for a perverse environmental effect is largely due to the accounting methodology required by the Kyoto Protocol, which refers to verifiable changes in carbon stocks within the first commitment period (i.e. between 1 January 2008 and 31 December 2012), including changes in carbon stocks from deforestation activities. A possible consequence of these accounting rules is that deforestation which occurs prior to 2008, such as in 2001, may not be counted and hence provides an incentive to undertake deforestation activities prior to the first commitment period. Possible mitigating factors against this perverse effect include existing environmental and land management legislation and policies, and the design of possible domestic policies to recognize credit for early action that reduces deforestation.

In addition, the dynamics of carbon stock changes may still result in some emissions from deforestation activities which occur prior to 2008 being counted. This is largely due to the lagged effect of emissions from some carbon pools such as soils, humus and coarse woody debris, which may result in an increase in CO_2 emissions for several years after the initial deforestation disturbance.

Further Analytical/Study Needs

While the studies carried out by the Forest Sector and Sinks Tables have advanced our knowledge of deforestation, there is still a high degree of uncertainty related to the estimates. Information on the areal extent, spatial location, carbon release and causes of deforestation remains limited and is a critical information gap. Deforestation estimates may be improved through further research, such as using remote-sensing technologies combined with statistical surveys. Further research into the design and implementation of effective policies to reduce deforestation is also needed, given the large range of activities and sources from different sectors which currently contribute to deforestation in Canada. However, the key data and definitional uncertainties need to be resolved.

3.5 Not Currently in Protocol: The Managed Forest and Carbon Stored in Forest Products

Under Article 3.4 of the Protocol, there is provision for negotiation on additional human-induced activities resulting in emissions from sources and uptake by sinks in forests. These activities would be added to those already permitted by the Protocol in the second and subsequent commitment periods, as well as in the first commitment period if the Party so chooses. As a result, various activities have been proposed that could enhance carbon sinks in forests. These include specific forest management activities such as thinning, fertilization and fire protection. The advantage of this approach is that it would enable recognition of incremental activities that increase carbon storage, even if Canada's managed forest is determined to be a source. However, some Table members feel that increasing the number of activities accepted under the Protocol would further complicate the methodology for accounting for verifiable changes in carbon stocks that could be attributed to these specific activities.

An alternative approach is to include all management activities within a specified area, such as the managed forest, and to conduct a full accounting of changes in carbon stocks within that area — including the impact of various forest management practices. This would be more consistent with sustainable forest management objectives being pursued by many countries including Canada, and is more complete in its treatment of sinks and sources than the current piecemeal approach of the RAD. This section does not consider the option of adding specific individual forest management activities to the Protocol, but discusses these activities within the context of the managed forest approach.

Issues related to accounting for other activities will be addressed in the IPCC Special Report on Land-Use, Land-Use Change and Forestry, due in the early summer of 2000, and decisions may be taken on Article 3.4 at CoP6 in the Fall of 2000. As such, it is important that Canada determine, as soon as possible, the net impact on its carbon balance of each negotiating option and determine which option it should promote in international negotiations.

A related but separate issue is the accounting for carbon stored in forest products. If a managed forest approach is adopted, then changes in carbon stocks due to harvesting activities will need to be accounted for. For a proper accounting of carbon stocks, the storage and subsequent decay of carbon in forest products is critical. Currently, IPCC guidelines assume that once a tree is cut, emissions occur immediately in that year. This is a gross oversimplification, as some biomass will decay on site, some will decay in landfill a little later, and some will remain stored for years as, for example, framing for houses. A number of options discussed in this section will only benefit Canada if the carbon storage in products is properly accounted for. In other cases, the proper accounting of products increases the benefit (or reduces the debit) from activities. There may also be an opportunity for modifying product mix decisions to reflect carbon storage impacts, although this would need to be balanced against many other objectives. In addition to accounting for the carbon stored in forest products, the issue of who "owns" the credits for exported products is obviously an important one for Canada.

Countries recognize the inadequacy of the current IPCC guidelines and have proposed alternative methodologies that have yet to be agreed to. As well, it is not yet clear whether or not the current IPCC guidelines will in fact apply to the accounting under the Kyoto Protocol, or whether new guidelines will be developed.

Clearly there is a biological limit to the increases in carbon stock that can result from changes in forest management practices or forest products strategies relative to current practices. Sooner or later, the carbon stocks of the managed forest and the forest product stocks will reach equilibrium and remain constant over time, assuming sustainable forest management practices and continued forest harvesting and protection. At this point, the carbon reservoir (in total metric tons of CO_2) may have been "permanently" increased but the sink (in Mt CO_2/year) is zero (i.e. sinks and sources are balanced). As such, the benefits of forest carbon sinks — as measured by changes in the managed forest — are not a "permanent solution" to emission reductions, but can provide a useful temporary measure, as changes in forest management enhance the amount of carbon sequestered over a period of time.

The work by Marland and Schlamadinger (1998) with the GORCAM model provides some useful insight, bearing in mind that the model is calibrated to U.S. conditions and models individual forest stands rather than the forest as a whole. The GORCAM model tracks all of the carbon stocks and flows impacted by forest management decisions, and includes storage of carbon in forest products, as well as fossil fuel use in harvesting, production of wood products and other substitute construction materials. The model shows that "although there can be significant storage of C in trees, soils, forest litter, and forest products, all of these C pools reach equilibrium over time and then provide no further C sequestration." Over the long-term, the main contributions of the sector come from the use of biomass fuels to displace direct fossil fuel uses and the savings of fossil fuels used to make product from energy intensive materials by using wood products instead. This is because, while "the C physically sequestered in the wood remains sequestered only for the lifetime of the product, the CO_2 emissions avoided by not using fossil fuels are avoided forever." These results are for a hypothetical forest and there are many differences between that and a real forest. The transitional effects of practices may be important in an actual forest.

3.5.1 Analytical Issues and Uncertainties

The Managed Forest

The managed forest approach means that <u>all</u> management activities within the managed forest are included and a full accounting of changes in carbon stocks is conducted within that area. This approach is consistent with encouraging the maintenance and enhancement of carbon sinks and reservoirs, which is an objective of the Framework Convention on Climate Change. It is more balanced in considering both removals from sinks and emissions from sources than the current provisions of the Kyoto Protocol (i.e. RAD). In addition, it is more consistent with sustainable forest management objectives being pursued by many countries, including Canada, and also appears to be more practical from a measurement and verification point of view.

Key uncertainties relating to a managed forest approach include:

- components of carbon stock
- definition and extent of managed forest
- emissions from man-caused and/or natural fires in or out
- accounting rules (for determining offsets to target)
- accounting for storage in forest products and how
- measurement and verification methodologies (ground measurement versus modeling)

The implications of a managed forest approach will vary by country, depending upon the age class structure of their inventory, extent of management for timber and other objectives, and growth rate of trees, among other factors. Carbon stocks on a country's managed forest may be increasing, decreasing or remain constant over time under current management regimes. For example, the U.S. has had increasing carbon stocks on its managed forest since 1990 due to both an increasing area of forest as well as increases in growing stock on that forest.

From Canada's point of view, the managed forest approach raises a number of questions that have yet to be resolved. This includes, for example, the definition of the managed forest in Canada. Current estimates range from 120 million ha to 235 million ha, depending upon one's definition, compared to the total area of forest in Canada of roughly 417 million ha. Some have argued that a large portion of this area should be considered managed because a conscious decision has been made to "not protect" the forest. However, Canada is different from most countries in that we have a forest industry that operates mainly in the natural forest under extensive (as opposed to intensive) management. Even second growth stands tend to be relatively unmanaged. The area of so-called managed forest in Canada is in fact likely to change over time, for example as product prices and changes in technology make areas economically accessible, and as environmental and conservation forces cause areas to be set aside for other uses.

Canada also has a very high natural disturbance regime compared to most countries. The Framework Convention on Climate Change, and the Kyoto Protocol to the Convention, focus on anthropogenic emissions only. As such, emissions from natural disturbances are not currently considered part of Canada's emission target. But it is unclear how CO_2 emissions from forest fires would be handled if the Protocol moved to a managed forest approach. It is estimated that Canada's forests as a whole (i.e. not just the managed forests) are currently a net source of CO_2, on the order of 69 Mt C per year, predominantly as a result of fire disturbance as noted earlier. Taking into account conversion of some of this carbon to forest products, net average annual emissions from the total forest are estimated to be about 45 Mt C/yr or 165 Mt of CO_2 equivalent (Kurz and Apps, 1999).

In addition, there is the uncertainty already mentioned about which and how many components of carbon stock will be considered under the Protocol (i.e. above-ground biomass, below-ground biomass, soil carbon). If the managed forest was included under the Protocol instead of (or in addition to) RAD, the carbon stored in forest products would need to be considered as well, since harvesting and production of products would be one of the key activities on the managed forest. We assume here that RAD would be a component of the managed forest (i.e. areas afforested would become part of the managed forest, deforestation would count as a debit, and reforestation, however defined, would also form part of the managed forest). In fact, if reforestation is defined as regeneration after harvest, then over a period of 100 years or so, the "Kyoto forest" will in fact equal the "managed forest" in Canada.

It should be noted that Article 3.4 of the Protocol states that parties will decide "...modalities, rules and guidelines as to how and which additional human-induced activities related to changes in GHG emissions and removals in the agricultural soils and land-use change and forestry categories, shall be added to, or subtracted from, the assigned amount for Parties..." This means that rules for adding additional activities and how they should be accounted for remain highly uncertain. It is not even clear that the accounting would be done using changes in carbon stocks in the commitment period, although that is what we are assuming for simplicity and for consistency with Article 3.3. A more meaningful option for including the managed forest would be the net-net approach. The net removals (removals minus emissions) from the managed forest in 1990 would be included in a country's baseline. The country would get a net benefit during the commitment period if the net removals had increased from 1990 and a net debit in the contrary situation.

Because of these uncertainties, it is difficult to estimate the BAU net removals in Canada under a managed forest approach. Preliminary work is underway using the Carbon Budget Model (CBM-CFS2), however this will provide only rough estimates under alternative scenarios, and much remains to be done in terms of modifying the model and improving the base data in order to come up with realistic estimates of carbon stock changes on the managed forest.

One possible definition of the managed forest is the 138 million ha included in the accessible non-reserved, stocked, timber-productive forest. An assessment was done using IPCC measurement guidelines, which are concerned only with anthropogenic emissions. Sellers and Wellisch (1998) estimated that a 123 million hectares area was a net sink of 45 Mt CO_2 equivalent in 1990, currently is a sink of about 30 Mt and will be a sink of about 10 Mt in 2010 (see Table 3.5.1). Sellers and Wellisch's estimate of -45 Mt in 1990 is for a 122.8 million ha managed forest area that excludes the overmature forest, which they assumed was not sequestering C. These results are based on the calculation methodology in the IPCC 1996 Revised Guidelines — other methodologies result in different results. As shown earlier, the entire Canadian forest was estimated to be a net source of 45 Mt/yr in 1990. The results in Table 3.5.1 exclude emissions from wildfires on the managed forest, as the long run impact of fires is assumed to be included as part of the average standing volume per hectare. Deforestation is also excluded. Care must be taken in using and interpreting this estimate as many assumptions had to be made. In addition, IPCC guidelines may be revised or new guidelines written, as noted earlier.

Table 3.5.1
1990 Emissions (+) and Removals (-) on the Managed Forest Under Current IPCC Guidelines

	Mt CO_2 /yr
Growth	-290
Harvest*	176
Slash	69
Net removals	-45

*Assumes immediate emissions in the year of harvest.
(Source: Sellers and Wellisch, 1998)

Industry representatives have long claimed that the growth of second growth forests in Canada is much higher than previously thought, and that estimates of average growth based on existing forests will underestimate the actual growth that is occurring on the managed forest. On the other hand, the total volume of carbon per hectare (i.e. the reservoir) is in general higher in primary forests, although there are some regional exceptions. These forests are likely to be considered part of the managed forest at the time of their first harvest, resulting in an initial reduction of carbon stock that may never be fully compensated for by subsequent regeneration, even though the productivity of second growth forests, in net carbon per ha per year, may be much higher. The lack of large-scale nationally accepted growth and yield information creates a problem for estimating potential gains from the managed forest under the Protocol. This information would also likely be needed in order to provide estimates of verifiable changes in stock within the commitment period, since "verifiable changes" will likely need to be estimated in part from models and not just actual ground measurements.

One further outstanding issue related to the negotiations needs to be resolved in order to determine the potential contribution of the managed forest for Canada. This is how CO_2 emissions from biomass energy would be considered within the Protocol. Currently, energy from biomass is considered to be CO_2 neutral. Much of the historic reduction in direct CO_2 emissions in the pulp and paper industry, and proposals for further reductions, are based on increased fuel-switching to biomass for energy from fossil fuels. The reason that biomass energy is considered to be CO_2 neutral is that it is assumed to come from a sustainable forest resource. Under a managed forest approach, a full accounting of carbon flows (including forest products and biomass as fuel) would take place, so that while the biomass energy would still offset fossil fuel use, there would likely be a requirement to track the CO_2 emissions. Thus, the impact for Canada of using the managed forest approach cannot be assessed without taking into account the industry implications.

As noted earlier, decisions related to negotiations will likely not be forthcoming until Fall of 2000 or later. However, it is important to consider the potential benefits of a modification to the Protocol that would look at changes in stocks on

the managed forest, and to consider the types of options that could be implemented to increase carbon stocks under such an outcome. There are various ways to increase carbon stocks in the managed forest that generally relate to: increasing growth rates (i.e. productivity), increasing rotation length, and increasing the maximum volume attainable on a site. There are complex interactions between these various factors, and increasing one while maintaining the others constant will increase carbon stocks, but increasing one at the expense of one or both of the others will not necessarily result in a net carbon benefit. In addition, it is important to consider the time dimension. In some cases, strategies may merely move the carbon through time with no overall net benefit, although this may be of interest from the point of view of obtaining credit for carbon earlier.

There has been some research on the impacts of alternative management practices to increase carbon stocks on forest lands. Most management activities have been studied from the point of view of impacts on merchantable volume — not total site biomass. What is clear from a review of this work is that the impact of various management strategies (e.g. thinning, spacing, fertilization, etc.) is species- and site-specific, and there is no one strategy that will fit all forest types and all regions (or countries). This makes it difficult to estimate the potential impact of putting in place policies that would facilitate these management practices. In some countries and regions, these management strategies are economic and are already used in order to increase wood supply, however, they are not currently used to a large extent in Canada.

Carbon storage in forest products

There are significant amounts of carbon stored for long periods of time in forest products. Paper, wood and other forest products contain carbon that was initially absorbed by the tree. Carbon is stored in forest products for varying periods of time depending upon its end use, before it decays and releases carbon back into the atmosphere. Depending upon the product produced, the carbon could be released very quickly or very slowly back into the atmosphere. For example, some wood and paper products (such as historical buildings and books in libraries) are expected to lock in carbon for longer periods of time than office paper products and wood pallets (see Table 3.5.2). Currently, IPCC guidelines assume that once a tree is cut, emissions occur immediately in that year, which in actual fact is only true for a small proportion of the carbon in the tree.

Converting mature forests into solid wood products locks in the CO_2 and prevents its release into the atmosphere. The carbon is released once the forest product has reached the end of its life cycle (i.e. begins to degrade) or is disposed as waste in a landfill or is burned (see Table 3.5.2). This process is part of the larger carbon cycle. The patterns of landfill decay are much different for wood than paper. Very little decay occurs to wood while in landfills so that the proportion of solid wood converted into CO_2 is very small (about 3%) even after very long time periods. Paper and newsprint, on the other hand, is subject to higher levels of decay resulting in a larger proportion converted into CO_2 (16 to 38%).

Table 3.5.2
Average Half-Lives of Carbon in Paper and Wood Products

End Use	Half-Life of Carbon* (years)
Single-family homes (pre-1980)	80
Single-family homes (post-1980)	100
Multi-family homes	70
Mobile homes	20
Non-residential construction	67
Pallets	6
Manufacturing	12
Furniture	30
Railroad ties	30
Paper (free sheet)	6
Paper (all other)	1

* Half-life is the time after which half the carbon placed in use is no longer in use.
(Source: Skog and Nicholson, 1998)

Of course not all wood that is harvested is converted into forest products. Some is left on site as slash and some is turned into waste on site at the mill, although much of this mill waste is either made into other products (e.g. chips into paper) or burned for energy (e.g. bark), or is landfilled. Proper accounting of these by-products is also required for a full accounting of carbon flows.

Whether the forest products carbon pool is growing (a sink) or shrinking (a net source) depends upon whether the amount of carbon harvested and processed into products is greater than the amount emitted in manufacture plus the decay of older products. If harvesting is increasing, the amount of carbon stored in the products pool grows quickly; if harvesting is relatively constant (like today) the products pool grows more slowly — but it still grows. The average annual growth in the products pool (new products minus manufacturing losses minus decay) from Canadian forests is 22.7 million tonnes of carbon (83.2 Mt CO_2). However, 17.4 Mt is exported to the U.S. and only 5.6 Mt stays in Canada. Possibilities to increase carbon storage in forest products include promoting longer use of forest products through recovery, recycling and reuse, and changing the focus of production to products with longer lifespans (e.g. less newsprint, more lumber). Whether Canada would obtain a benefit or not from expanding forest product carbon pools would depend upon the measurement and accounting systems used. An important issue here, particularly given the Canadian industry's reliance on export markets, is who would receive the credit for the storage of carbon in products, and any debit for the eventual emissions — the importer or exporter.

3.5.2 Modifying Forest Management Practices to Increase Carbon Sequestation on the Managed Forest

There are a number of potential actions that could increase the net carbon stock of the managed forest, and therefore, increase the net potential contribution of the managed forest to Canada's emission reduction target, **assuming that the negotiations result in a requirement to report and use as a potential offset, the changes in stock on the managed forest in the commitment period.** Clearly, any changes to current practices should be done in the context of sustainable forest management, and should not promote carbon sequestration at the expense of other environmental or sustainable development objectives. It is also clear that practices which increase CO_2 sequestration may or may not be the same as those that increase merchantable timber supply volume for industrial use.

Forest management strategies which have been proposed for increasing carbon sequestration include:

- reducing the regeneration delay after natural disturbances or harvest through planting or seeding;
- restoration of degraded sites and not sufficiently restocked (NSR) lands;
- use of genetically enhanced trees;
- fertilization;
- control of pests and diseases;
- increased protection from fire (addressed in section 3.5.3);
- commercial thinning;
- juvenile spacing;
- increasing rotation age;
- changing species mix (e.g. planting fast-growing, short-rotation hybrid species);
- reducing harvest levels (i.e. set-asides); and
- changing harvest methods.

Some forest management strategies, such as commercial thinning and juvenile spacing, may maintain or reduce the on-site carbon immediately after the activity, and provide their major benefit after harvest, by increasing the carbon stored in forest products or by allowing some stands to remain that otherwise would have been harvested. While planting and use of genetically enhanced trees will directly increase carbon stocks in the first few commitment periods and beyond, the carbon benefits from thinning and juvenile spacing can only be achieved over a rotation (i.e. 40 to 60 years). In order to obtain benefits in the first and subsequent commitment periods, accounting rules that allow for the amortization of benefits over the rotation or the incorporation of credit for carbon storage of forest products, may be needed.

Intensive forest management practices will tend to increase the average productivity of the forest (i.e. in m^3/ha/year). The total impact on forest level standing carbon stocks is difficult to conceptualize, because of the transitional effects over time. Among other things, these transitional impacts are dependent upon the age class distribution of the forest, the age at which the treatment is applied, how long the impact of the treatment is, and whether or not there is an allowable cut effect that permits an increase in harvest immediately after an investment in silviculture is made. However, the overall result of most of these intensive forest management activities will tend to be a one-time increase in standing carbon stocks on the managed forest as a result of increases in productivity — even if in the long-term there is an increase in harvest equal to the increase in growth.

The carbon-sequestering potential of specific forest management activities has been estimated by the Canadian Pulp and Paper Association (CCPA), considering only the carbon in above-ground forest biomass. Most estimates of carbon sequestration benefits are based on preliminary calculations of commercial (i.e. merchantable) forest volumes and often fail to account for the impacts of the activities on all ecosystem carbon pools. More in-depth scientific study is required to confirm the carbon impact considering all carbon pools, including soils. Few studies have assessed the economic implications of forest management activities for incremental CO_2 sequestration.

Reducing Regeneration Lag and Restoration of Degraded Sites

Planting to regenerate a forest after harvest, instead of (or in addition to) aerial seeding or natural regeneration, accelerates the process of stand establishment and permits the capture of carbon gains developed through tree improvement programs. Planting or other site preparation after natural disturbance can also reduce the regeneration lag for re-establishment, although consideration of other values such as biodiversity and aesthetics, as well as costs, need to be considered carefully. The rule of thumb is that planting provides a 10-year advantage over natural regeneration. No estimates of potential have been made at this time. Currently, about 45% of harvested areas are planted in Canada. See also the discussion in section 3.3.2.

There is also the potential to rehabilitate or restore degraded sites, or areas that have not previously regenerated successfully after harvest (i.e. NSR lands). These areas are still considered part of the managed forest. Many of these areas have regenerated to non-commercial tree species and shrubs, so that an assessment would be needed to ensure that net carbon sequestration was increased.

Genetic Tree Improvement

Genetic tree improvement is a term for developing, producing and planting faster-growing stock, usually through a process of tree selection and production of superior planting stock. Genetic tree improvement programs can increase the rate of growth, as well as pest and disease resilience of seedlings produced for planting programs. If growth was increased by 15% through the use of genetically enhanced stock on all areas planted/seeded since 2000, the sink capacity in the first commitment period would be approximately 0.5 Mt CO_2, but would increase substantially over time. The analysis by the CPPA shows a much higher benefit of 2 Mt of CO_2/year in 2008-2012 although they assumed that only 50% of all planting will employ enhanced seedlings. This higher estimate reflects an assumption of much higher growth rates for young trees.

Fertilization

Fertilization has been shown to provide a significant increase in growth if applied 10 to 15 years before final harvest on some sites. A net carbon budget needs to be determined to see if the increase in carbon sequestered more than offsets the carbon used to produce and apply the fertilizer. Opinions on this vary in the literature. The long-term impacts of fertilization on total site biomass have also not been studied (i.e. understory, root biomass, soil carbon, etc).

Pest and Disease Control

Pests and disease account for wood volume losses on the order of 61 million m^3 per year, compared to 170 million m^3 for harvesting and 88 million m^3 for fires. Some pests and diseases can be controlled or reduced by spraying biological or chemical pesticides, but application of pesticides has declined in recent years due to environmental and health concerns. Reducing damage from pests or disease allows the mortality to be "captured" so that the forest is harvested and the carbon stored in forest products (and it can also mean that another forested area was not harvested). The CPPA estimates that this is one of the cheapest options for increasing carbon stocks on the managed forest, and that an estimated 6 Mt/year (or one third of the annual volume loss) could be saved by large-scale spray programs, at a cost of $0.75/ton of CO_2. This figure is based on an assumption that the carbon credit would be equal to the volume of the trees that have been 'saved', and does not consider the implications of repeated spray applications on a particular site over the life of the trees. Besides the environmental and health concerns, there is a great deal of uncertainty about the long-run impact of spraying on pest populations and the biomass accumulation impacts including the impacts on understory vegetation and endemic levels of the insect or disease being sprayed for, as well as other insects and diseases.

It is clear, however, that under a managed forest approach where changes in carbon stocks are used to offset Canada's target, the issue of enhanced protection of forests to avoid significant pest and disease losses will need to be examined from a strategic perspective. Reducing mortality and losses from natural disturbance may, in some areas, be a cost-effective option. However, substantially more work and more information is needed on this topic before options can be recommended.

Commercial Thinning

Commercial thinning is the harvesting of a portion of a stand before it reaches rotation (normal harvest) age. Thinning involves the removal of trees that would normally be lost to mortality at an intermediate stage in the growth of the stand. Thinning does not result in a greater amount of standing biomass at rotation age, but it results in a higher yield over the rotation period, because of utilizing both the thinnings and the final harvest. The thinning volume removed is converted into products, thus storing the carbon in potentially long-term storage such as lumber and other wood products.

Commercial thinning also offers the benefit of extending wood supply, in the sense that a higher volume per hectare can be achieved from a hectare over the rotation, thus leaving uncut other stands that might otherwise have been harvested.

While current rates of commercial thinning are very low in Canada, increased commercial thinning to 200,000 ha per year could sequester an additional 26 million tonnes of CO_2 over one rotation according to preliminary estimates by the CPPA based on two species only. Because we are assuming that a managed forest approach would be measured based on changes in stock in the commitment period, this carbon benefit would likely only be a positive benefit if the carbon stored in forest products (i.e. from the thinnings) counted as carbon stocks, or if the wood from commercial thinnings reduced harvest activities elsewhere. An added benefit from efforts or incentives to increase commercial thinning would be the potential reduction in use of clearcuts in some areas.

Further work is needed to assess whether the increased thinning activities would result in reduced input of coarse woody debris into the dead organic matter pools of the ecosystem. One silvicultural objective of thinning is to capture the biomass that would otherwise be lost through tree mortality. In achieving this objective, less biomass carbon will be added to dead organic matter pools and these pools will therefore contain less carbon in thinned than in unthinned stands. If the reporting guidelines for the Kyoto Protocol include both biomass and dead organic matter pools, then the net benefit of thinning will be lower than if only the biomass pools are assessed. And if carbon stored in wood products is not included in the Protocol, then thinning may not be a beneficial activity from the point of view of carbon.

Juvenile Spacing

Juvenile spacing is the thinning of dense juvenile stands (10 to 20 years old) to ensure that all trees have enough room to grow and develop at optimum rates. It is often useful for adjusting species mix to help achieve biodiversity, sustainable practices and other management goals. Spacing tends to increase the average diameter of stems and achieve higher merchantable volumes, but not necessarily increased biomass at rotation age. Producing higher levels of merchantable volumes may also increase carbon stocks if carbon in forest products is included (e.g. if more lumber can be produced). However, juvenile spacing can also reduce rotation age, allowing harvesting to take place at a younger age and can also increase growth in forests that are stagnating from high levels of competition.

The CPPA estimates that current rates of juvenile spacing are 375,000 ha/year. This will increase carbon sequestered by increasing the yield of forest products from a given area over time by 50% (e.g. over the same time period, there are three rotations instead of two on the same area). In other words, these 375,000 ha/year will produce the same amount of forest products as 560,000 ha/year of unspaced sites do today. At an average of 240 tonnes of CO_2/ha at rotation, this is a savings of 44 megatonnes of CO_2 (240 tonnes/ha x 185,000 ha/yr). Alternatively this can be viewed as an increase on average of 1.6 t/ha/year over approximately 150 years. This means that carbon stocks will increase overall if credit is given for forest products carbon storage, or if the harvested area of the managed forest is reduced overall (i.e. the increase in harvest volume due to spacing is used to offset volumes from other areas). The above estimates are based on one species only.

Spacing programs are estimated, by the CPPA to cost in the range of $4/tonne CO_2 but there are additional factors and benefits such as larger diameters and lower rotation age which might improve the cost/benefit profile of the activity for industry. In addition, regional variation in species and sites mean that the response to juvenile spacing varies widely across Canada.

Increasing Rotation Age

Increasing the rotation age of a stand will tend to increase the standing volume of the stand (assuming that the stand has not yet started to decline). Substitution of long rotations for short ones will increase the average volume of carbon sequestered in trees (assuming no change in disturbance regime, etc). Again, it is not clear that total carbon on the site increases overall when other carbon stocks, such as understory, are included. Considered over the entire forest, a lengthening of rotation age on all stands might have an impact on the harvestable volume of the forest, although this would depend upon the age structure of the forest, harvesting methods, current rotation ages, etc. When CO_2 or other

non-timber benefits have a positive value, then studies have shown that in fact the "optimal rotation age" lengthens compared to what it would otherwise be when only timber benefits are considered.

Reducing Harvest Levels

Reducing harvest levels and/or setting aside areas of protected forests for carbon sequestration or other purposes may or may not increase standing volumes and carbon stocks. The impact is likely to be greatest if harvesting is reduced in regions where natural forest succession and growth results in stands that are longer lived or higher in volume than would be the case if the areas were harvested on a rotation cycle designed to maximize fibre flow. Again, the impact would depend upon such things as the interval between natural disturbances compared to the rotation age at which the stand would otherwise be harvested, the average age and the age distribution of the forest, the species, region etc., and the type of forest product produced after harvest. The economic cost of reducing harvest volumes could be significant (i.e. a high opportunity cost). In addition, if the area was to be protected, then there would be a protection cost. Over time, the forest would likely age and decline, with subsequent losses of forest carbon to the atmosphere, or, if the area was a mix of age classes, then a steady state would be achieved with no net losses or gains. Recent studies have also shown that reducing or delaying harvests may not have an impact on the carbon in the atmosphere, because of increased harvests elsewhere in the world. Increased use of more energy intensive product substitutes could also result in increased net emissions.

Summary of Impacts on On-site and Off-site Carbon

Changes in forest management practices will impact both the on-site carbon (i.e. trees, vegetation, etc.) and the off-site carbon (i.e. stored in forest products). It will also affect energy inputs - for example, increased use of planting for regeneration after harvest will tend to increase fossil fuel use compared to natural regeneration. Table 3.5.1 attempts to summarize the stand-level impacts for various groups of forest management practices, and highlights the complexities of this issue. Impacts vary depending upon the time scale (short-term/long-term) and whether the increase in volume is used to displace harvests from other areas (i.e. the total harvest level is unchanged) or is used to augment the harvest level.

There are also important transitional impacts at the forest level that are not reflected in these stand-level impacts. The standing volume of the total forest overall may increase or decrease over time as a result of stand treatments but the effect will depend upon many interrelated factors such as age class distribution, species, etc. Stand level impacts are easier to conceptually understand than forest level impacts because of these transitional impacts.

Table 3.5.1
Summary of Stand-Level Impacts on On-Site and Off-Site Carbon

Activity	Impacts on On-Site Carbon		Impacts on Off-Site Carbon		Impact on Energy Inputs	
	Trees Only	Above- and Below-Ground Biomass	Harvest Level Constant	Harvest Level Increased	Harvest Level Constant	Harvest Level Increased
Planting, genetic tree improvement, fertilization	short-term positive, long-term variable	unknown	neutral or positive (if can produce more long-lived products)	positive	increased	increased
Commercial thinning	short-term negative, long-term variable	unknown	neutral or positive (if can produce more long-lived products)	positive	neutral or increased	increased
Juvenile spacing	Short-term negative, long-term neutral or positive	unknown	neutral or positive (if can produce more long-lived products)	positive (if can produce more long-lived products)	neutral increased	neutral increased
Pest and disease control, fire control	Short-term positive, long-term unknown	unknown	neutral	positive	likely increased	increased
Increased rotation age, reduced harvest levels	positive if natural disturbance regime less frequent than harvesting cycle	unknown	Negative (but may be neutral globally)		reduced, but indirectly may increase energy use if reduced harvest increases use of more energy intensive products	

3.5.3 Fire Protection

Natural disturbances, such as fire and insects, play an important ecological role in the dynamics of Canada's forests and have a huge impact on biomass accumulation and emissions. It should be emphasized, however, that the Framework Convention on Climate Change, and the Kyoto Protocol to the Convention, focus on anthropogenic emissions only. As such, emissions from natural disturbances are not considered part of Canada's emission target. There are several issues to be considered. One is how CO_2 emissions from fires would be handled if the Protocol moved to a managed forest approach. The second is whether increases in fire protection would be cost effective for increasing carbon storage. The final question is whether Canada should investigate obtaining credit for forest carbon protected from fires, as a separate activity under the Kyoto Protocol.

Forest fires release carbon at the time of disturbance, transfer carbon from live biomass to dead organic matter pools, and reset ecosystem dynamics to a regenerating stand. They therefore play an important role in ecosystem carbon dynamics, both at the time of disturbance and in subsequent years. Because fire is a part of forest ecosystem dynamics, the release of carbon from forest fires needs to be considered when accounting for carbon stock changes. The impact on the reported carbon stock changes depends on the location of the fire. Carbon releases from fires outside the managed forest would not be reported from a "Kyoto Forest" perspective. Fires within the managed forest would likely affect the carbon stock changes that could be reported under Article 3.4.

With increasing frequency of stand-replacing disturbances, the landscape-level carbon storage decreases (Kurz *et al.*, 1998). Reducing fire frequency (e.g. through suppression efforts) will increase landscape-level carbon storage, and fire protection has been suggested as a possible method for increasing carbon storage (Sohngen and Haynes 1997). The increase in carbon storage in tree, forest floor and understory biomass carbon pools from a 5% reduction in the area burned was about 0.5 Mt C/y (or 1.8 Mt CO_2/y). The study did not address any questions related to the accounting of such carbon increases under the IPCC guidelines.

In addition, if the natural disturbance is replaced by harvesting and the storage of carbon in forest products, there may be fewer emissions. For example, application of the CBM-CFS2 model to a boreal forest management unit near Hinton, Alberta showed that management and harvesting may increase the carbon reservoir of the forest (Price *et al.*, 1997). The key is a harvest rotation length that is longer than the natural disturbance cycle, accompanied by protection against fire and other losses, so that natural disturbances are replaced by harvesting. This result depends on the type of forest. Managed secondary forests in B.C., with rotation lengths well below the typical life span of two or more centuries for natural forests, likely have much less total carbon storage than the natural forest.

Current Situation

During the 1990s, an average of about 8,500 forest fires burned over an area of about 2.9 million hectares of Canadian forest land annually. While the number of fires varies significantly from year to year (generally between 6,000 and 11,000), the total annual area burned is highly episodic and can fluctuate by an order of magnitude (e.g. 0.62 and 7.10 million hectares in 1997 and 1995 respectively). In most years, the vast majority of the area burned occurs in large fire observation zones (i.e. areas of extensive or modified suppression) where fires are monitored but not actively suppressed unless values (e.g. communities, recreational facilities, industrial sites) are at risk. These zones are located in the northern regions of Saskatchewan, Manitoba, Ontario and Quebec, and throughout Northwest Territories, Yukon and Newfoundland (Labrador). An average of 6.4% (3.7-10.7%) of the 1990 to 1998 fires occurred in observation zones, accounting, on average, for 65% (51.3-87.2%) of the total area burned in Canada. The remaining 35% of the area burned in the intensively protected forests (assumed to be equivalent to the "managed forests") during this period, an average of slightly more than 1 million hectares per year.

Nationally, about 35% of fires are caused by lightning, and these fires account for about 85% of the total area burned. The remainder are caused by humans. Roughly 95% of fires occurring in the observation zones are lightning-caused (a reflection of low population densities). Approximately 97% of Canadian fires under 200 hectares in size are controlled, but the 3% of fires that grow larger than 200 hectares account for about 97% of the area burned nationally. Fire management agencies configure their resources to detect fires early and keep them small through aggressive initial

attack, particularly in the intensively protected forest zones. Generally 3-4% of fires escape initial attack, primarily due to multiple ignitions or extremely intense fire behavior (or both) stretching and overwhelming available suppression resources. Provincial and territorial fire management agencies in Canada expend an average of around $500 million annually.

Options for Increasing Fire Protection

The inclusion of carbon sinks in the Kyoto Protocol has resulted in an evaluation of the carbon sequestration potential of Canadian forests, particularly as an offset for fossil fuel emissions. While the range of forestry activities currently included in the Protocol is limited, there is scope for negotiations on broadening this under Article 3.4. In this regard, there have been suggestions that we should be obtaining credit for fire protection (i.e. that we should get credit for the reduction in carbon dioxide released relative to what would have happened without protection). This also brings up the question of the possible costs and benefits of increased fire protection as a means of reducing fire losses and increasing carbon storage in forests.

It is useful to examine these issues separately for the intensive protection zone and the extensive protection or observation zone. It should be noted that the intensive protection zone is consistent with the "managed forest" although there is not a one-to-one correspondence (and, in fact, there is no agreed-upon definition of what the managed forest in Canada is, or what size it is).

Observation Fires Zone

Fire is a natural disturbance in Canada's forest, essential to ecosystem maintenance and productivity through its influence on landscape diversity and biogeochemical cycles, particularly the carbon cycle. Fire management agencies have long recognized that excluding fire is neither ecologically desirable nor economically feasible. The generally practiced policy of modified suppression in observation zones is a reflection of this awareness.

Opportunities to sequester more carbon through an extension of intensive protection into current observation zones are not likely to be viable for the following reasons:

i. fire is natural in Canadian forests and global biodiversity concerns dictate that a certain amount of fire be maintained in these ecosystems;
ii. forests in these zones are largely unmerchantable, particularly when the cost of access and wood extraction is considered;
iii. fire protection in these remote regions would be extremely costly (infrastructure establishment and maintenance) and likely much less effective due to longer detection and response times; and
iv. current climate change scenarios indicate increasingly severe fire weather conditions, more frequent and extreme fire activity (particularly lightning fires), and significant changes in forest structure and carbon storage in northern Canada, making the effectiveness and carbon benefits of increased protection efforts highly uncertain.

Intensive Protection Zone Fires

The Intensive Protection forest zone in Canada includes all of B.C., Alberta and the Atlantic provinces, and the southern and central regions of Saskatchewan, Manitoba, Ontario and Quebec. In this area, forests are used for both industrial and recreational purposes, and fire management agencies actively suppress fires to ensure the protection of human life and property, and a continuous timber supply from economically valuable industrial forests. The vast majority of fire management resources are focused on intensive protection of these assets, and fire management agencies are generally successful in reducing fire impacts in these regions. Is it possible to effectively increase protection in these forests? There are a number of reasons why this is doubtful.

Fire cannot be eliminated, as extreme fire weather conditions often create unmanageable situations (multiple ignitions and intense fire behavior) and fires escape initial attack. Once fires escape, the effectiveness of further and more costly suppression activities is severely compromised, and many fires run their course. As well, agencies do not budget for extreme situations, as these are intermittent, and would require infrastructure costs that would be unwarranted most of the time. The law of diminishing returns definitely applies here, where increased expenditures do not guarantee increased success.

Fire management agencies use sophisticated models to preposition and allocate resources throughout the fire season. One such model LEOPARDS has been developed recently and is currently in use in Ontario. LEOPARDS is a theoretical model that determines the relationship between fixed costs (expenditures associated with pre-suppression planning, permanent resources, infrastructure) and variable costs (out-of-pocket expenditures associated with the severity of the fire season, additional resources required, etc.), and the initial attack success rate on fires. This model shows that the number of fires that escape initial attack levels off at about 4%, even if fixed and variable costs are increased beyond a certain optimum level. Assuming Canadian fire management agencies — despite cutbacks in the early 1990 — are operating at the most effective mix of fixed and variable costs, it seems safe to assume that increasing protection expenditures will have little effect on the percentage of fires escaping initial attack.

The LEOPARDS model was recently used in a hypothetical study in Ontario, and results indicated that an increase of $7 million in fixed costs would save $3.5 million in variable costs, but that this net expenditure of $3.5 million would only result in a decrease of 1% in escaped fires, even though Ontario was not operating with the most optimum mix of fixed and variable costs in this model run.

Before carbon sequestration became a major issue, Canadian fire management agencies had ample reasons and opportunities to investigate the impact of protection expenditures on wood supply, and likely gravitated to an optimum level and mix by trial and error.

Conclusions

Some have argued that fire suppression should be considered under Article 3.4 as an additional activity. The carbon sequestration gains from preventing forest fires, however, are not readily calculated and are not verifiable. Against what baseline of area annually burned would the success of fire protection be measured? How would one verify the "prevented decrease" in carbon stocks?

It has been suggested that a baseline of expected annual area burned could be calculated and fire suppression efforts could lead to carbon credits if the area burned is less than the baseline (CPPA, 1998). The high between-year variability in the area annually burned makes such an approach difficult to implement. Moreover, the three fold increase in the area annually burned in Canada during the decade of the eighties occurred while fire protection was in effect. Even if one could calculate a baseline of the expected area burned, how would one deal with future increases in the area burned due to factors beyond human control? Would the carbon sink credit in low fire years be offset by emissions in high fire years?

An additional question is whether man-cause fires would cause a carbon debit to be incurred, if fire suppression were to be negotiated into the agreement. While 15% of area burned is currently from man-caused fires, this figure is likely substantially higher when considering only the managed forest. In addition, the attribution of fires to natural or human causes is not always straightforward.

Seeking credit for successful protection is an extremely risky undertaking in countries like Canada and Russia with large forest resources. Fire impacts are highly variable from year to year, and accepting responsibility for protection means running the risk of major carbon debits in significant fire years, something likely to become more common under projected levels of climate change. Given these and other carbon accounting issues, it must be anticipated that protection is not likely to be considered as an additional forestry activity under the Protocol. However, under a managed forest approach, countries may be responsible for emissions from fires on their managed forest. In this case, a careful review and analysis of the costs and benefits of increased fire protection on the managed forest would need to be considered.

3.5.4 Modifying Forest Products to Increase Total Carbon Stocks

As noted earlier, there are actions that could be taken to specifically affect the carbon stocks of forest products. The benefit to Canada would depend upon whether carbon from forest products are considered part of carbon stocks for offsetting against the emissions targets, as well as the accounting/measurement system used to track carbon stocks (e.g. who gets credit for the carbon in exports of wood products).

Changing Product Mix

If carbon stored in forest products is included in the Kyoto Protocol, then strategies to modify the product mix in order to increase the length of time that carbon is stored before it returns to the atmosphere, could be implemented. These could include producing more long-lived products such as lumber as opposed to paper products. Obviously the markets would be need to assessed as well as the suitability of the trees. Currently, most wood is processed by a sawmill first, with the residues going to pulp and paper mills, so the scope for this option appears limited.

Increased Recycling

Recycling of both wood and paper products slows the carbon cycle. Wood or paper which is re-used to produce further products is delayed from going to landfill or otherwise decomposing. It also replaces wood that would be harvested from the forest. However, before recommending increased recycling for the purposes of increasing carbon stocks, a complete carbon accounting of paper recycling in Canada is needed, since wastepaper often must be transported long distances in order to be recycled, which consumes fossil fuels.

3.5.5 Further Assessment of Managed Forests and Carbon in Forest Products

Impediments to Implementation and Policy Requirements

There are many factors that limit the more widespread use of the various forest management activities described above to increase carbon stocks on the managed forest or off site. These include:

- uncertainty surrounding tenure security of public land for companies which are reluctant to invest in activities to increase future wood supply unless they know they will have the right to harvest the wood;
- costs (most activities are not currently economic on many sites); and
- lack of official recognition of growth and yield benefits of these activities. Increasing growth rates through investments in silviculture do not currently translate into increases in allowable cuts.

In addition to these more general impediments, there are impediments that are specific to the carbon sequestering potential of these activities:

- exclusion of these activities under the Kyoto Protocol
- unresolved ownership carbon rights on public lands
- lack of definitive scientific estimates of carbon benefits
- uncertainties about tree growth rates and measurement requirements for reporting
- lack of knowledge about offset opportunities

The types of policies that could help address some of these general barriers include:

- government recognition of volume benefits of management actions and subsequent revision of annual allowable cuts (AAC effect).
- provincial settlement of land tenure issues for the long-term, or agreement to offer compensation to companies that increase growth rates through silviculture treatments to enhance growth, yet lose the right to harvest it
- establishing lower stumpage rates for commercial thinning to offset higher costs compared to normal harvesting

Policies related to carbon credits include:

- negotiation of managed forest or additional forestry activities into article 3.4 of the Kyoto Protocol
- resolving carbon rights ownership on public lands
- incentives and policies to reduce costs
- research to better establish the carbon impact of activities across different sites, species and rotations through extensive analysis of existing data and development of comprehensive growth and yield data, including growth and yield data for second growth forests and managed stands
- creating a clearing house for carbon offsets, including those from forests

Clearly further work on policy needs will be required, as the basic information base on impacts is improved and as the negotiation outcomes become clearer.

Regional and Intra-Sectoral Implications

As noted earlier, the impact of these various changes in management practices will vary across regions depending upon species and site conditions. The main forest product-producing provinces are B.C., Quebec, Ontario and Alberta, although forestry is also important economically in most other provinces.

Competitiveness, Economic and Social Implications

These various forest management activities will result in greater employment opportunities, contributions to stability and well-being of rural communities, increased forest growth and wood supply, and environmental benefits. Forest management activities can contribute to economic sustainability and job creation, through the employment of students and members of First Nations, especially in disadvantaged regions. These programs further support economic sustainability by maintaining or improving the wood supply for the wood products industries, and therefore, the viability of local sawmills and pulp mills. Increases in wood supply in general can provide an opportunity to increase the forest sector's contribution to the economy. The forest industry is by far the largest contributor to the country's balance of trade, and the largest industrial employer.

Many of these activities are likely cost effective on a cost/tonne CO_2 basis. However, our knowledge of impacts on all carbon pools is limited, in particular the long-term dynamics of the various pools. Many of these activities enhance the volume of standing wood and hence other values need to be considered (e.g. increases in stumpage paid to governments by companies resulting from increased harvests).

Environmental and Health Impacts

Modifying forest management methods to focus on increased CO_2 sequestration may result in a range of environmental costs and trade-offs with other forest management objectives. These potential trade-offs include: biodiversity conservation and ecosystem management objectives (e.g. provision of stand structural diversity and habitat); aesthetic landscape and recreation planning; stream and water quality considerations; and long-term regeneration objectives (e.g. use of native tree species to minimize biological risks and diseases). The precise nature and extent of these types of trade-offs is uncertain and is an important information gap. It should be noted that some of these activities will increase the use of fossil fuel (see Table 3.5.1), particularly if increases in volume are used to increase overall harvest levels. In addition, increases in harvesting will result in increased emissions from processing. Increases in biomass could increase the use of biomass energy, with positive net benefits relative to fossil fuel use. Increased production and use of wood products may provide an indirect environmental benefit if used to replace more energy-intensive building materials such as concrete.

There is some evidence that activities such as juvenile spacing can result in added soil nutrients where thinnings are cut and left to decay on site. It can also result in suitable habitat for wildlife, as shown in some studies (e.g. high populations of spruce grouse and hares have been shown in previously spaced forests).

Extent of Use of Same or Similar Actions/Measures in Other Countries

The American Forest and Paper Association actively supports the inclusion of existing forests and forest products in carbon accounting for meeting Kyoto targets. This option is also supported by the International Forest Industry Round Table, consisting of Australia, Brazil, Canada, Chile, Finland, New Zealand, Norway, South Africa, Sweden and the U.S.A. In March 1999, the *Chafee Bill* was tabled in the U.S. Senate for discussion. This bill would give regulatory credit for voluntary action to reduce GHG emissions and also would recognize enhancements to carbon reservoirs as carbon credits.

Further Analytical/Study Needs

While a preliminary review of the literature showed a large number of studies on above-ground merchantable volume impacts for specific species and regional cases, further analytical work and basic data collection is needed in order to determine the impact of these various actions on all carbon pools, and to assess the impact for all species and sites across Canada. Difficulty in obtaining consultant bids on this topic reflected the general lack of expertise and information availability on this issue. Even determining the BAU estimates proved difficult, because those analysts with the potential tool for analysis were already fully engaged in other Table work or work related to the IPCC Special Report on Land-Use, Land-Use Change and Forestry. Further work will continue on modifying the CBM-CFS2 model and database to permit scenario analysis on the BAU estimates under the managed forest approach. However, much work remains to be done on the basic data collection, including growth rates of the second growth forest, analysis of carbon impacts of management interventions and other environmental impacts. Analysis of net impacts taking into consideration fuel use for increased management activity is needed.

Relationship to Other Actions/Measures

Actions to increase carbon sequestration from reforestation are also applicable under a managed forest approach. Reducing deforestation on the managed forest is also clearly relevant. Areas that are afforested may be considered part of the managed forest. As well, timber from afforested areas could be used to offset reductions in the Allowable Annual

Cut due to lengthening rotation age, avoiding harvesting in primary or high-volume forests or other carbon-related set-asides, although there would be significant logistical and legal obstacles to be overcome.

Stakeholder Views

Most Table members agreed that the managed forest approach made sense to pursue. There was concern expressed by some members (especially industry representatives) that insufficient analysis had been done in this area by the Table, given the perceived high potential sequestration benefit of various actions under the managed forest approach.

All agreed that more analysis was needed on this approach, and that negotiations should proceed with caution until the net impacts for Canada are determined. However, industry members were particularly concerned that policy measures and incentives be put in place sooner rather than later, to encourage voluntary behavior to enhance carbon stocks, even without the 100% assurance that the managed forest approach would be adopted in the Protocol.

3.6 Conclusions and Recommendations

Caveats in the estimates include the following:

- The afforestation estimates are based on the best available information given the timeframe allowed for the analysis, but there are still large data gaps and basic information needs that render many of the results uncertain. For example, we could not provide a full accounting of costs and benefits. Costs which we did not include are the costs of forest protection, program operation, and monitoring and verification of carbon sequestration, as well as the cost of potential future carbon debits. The benefits which we did not include are in large part dependent on the eventual use of each afforested area — for example, they could include environmental benefits related to restoration of degraded or fragmented forests, or revenues from harvesting the trees for use in forest products or for bioenergy. There would also be a variety of local employment and economic diversification effects; and

- The afforestation results are based on initiating afforestation in 2001 with a ramp-up to full annual planting targets by 2005. The ability to begin large-scale afforestation programs in 2001 is a very optimistic assumption - start-up in 2002 or 2003 may be more reasonable given the time that will be needed to develop and promote afforestation programs, obtain seedlings and involve landowners. Such a delay will lower the carbon sequestration in the first commitment period; and

- Negotiation outcomes will be a key determinant of the net impacts of reforestation, afforestation, deforestation and additional forest management activities on Canada's target in the first and subsequent commitment periods.

3.6.1 Recommendations for Measures

The Climate Change Secretariat guidelines for options analysis provide for four categories of measures:

- measures that can be implemented immediately (i.e. in 2000) and should be part of a package of core measures in Canada's national strategy to reduce its emissions in 2008-2012;

- measures that should play a role in Canada's strategy but which, for example, require further analytical work and/or broader consultations or are conditional on international developments;

- measures that merit further consideration but are longer term and require additional analysis and information; and

- measures that do not merit further consideration.

The Sinks Table recommends only category 1 and 2 forestry sinks measures, noting that itself and the Forest Sector Table did not fully developed measures per se but rather "actions" in that no detailed specific program, support, etc. is proposed to facilitate the "action."

Recommendation 3.1: an afforestation program to plant about 50,000 ha using fast-growing tree species should be implemented immediately as a category 1 measure.

Key impediments include high up-front costs and uncertain participation rates. While more expensive to establish than afforestation using other species, the use of fast-growing species would increase the amount of carbon sequestered in the first commitment period. In general, there is still considerable uncertainty about the potential involvement of landowners and others in afforestation, as well as the cost and impact of afforestation, especially in the first commitment period. It is likely that the forest products industry will be very interested in participating in this type of afforestation and will use the wood either for energy or products such as oriented strand board. A substantial amount of planning would be required to ensure that afforestation was carried out on appropriate sites, and that program incentives were appropriate.

There are a variety of carbon accounting issues which still need to be resolved through negotiations because of the likelihood that fast-growing tree species will be harvested in or soon after the first commitment period. The implications for carbon credits under alternative negotiation outcomes would have to be further investigated, as part of afforestation program development. It should also be noted that only verifiable changes in carbon stocks will provide carbon credits, so a measurement and monitoring system will be a necessary component of any afforestation program.

Recommendation 3.2: afforestation programs to plant about 800,000 ha in block plantations and shelterbelts using traditional tree species should be implemented immediately as part of category 1.

Key impediments include high up-front costs and uncertain participation rates. While the major impact is of a longer term nature, the earlier that programs are developed and implemented the earlier will be the impact. It should be noted that under some international negotiation outcomes, shelterbelts may not be included under a definition of afforestation (or reforestation).

Recommendation 3.3: policies to reduce deforestation should be part of Canada's post-2000 strategy (category 2) since emissions from deforestation in 2008-2012 must be added to Canada's target.

Key impediments include the lack of information on the extent and causes of deforestation. There is a high degree of uncertainty about the extent, causes and location of deforestation. However, it is likely that strategies for reducing deforestation in some areas will be more cost effective in the short term than afforestation policies. Adjustments to policies must be done cautiously, taking into account economic and other tradeoffs, and much work is needed to better quantify and define the causes of current rates of deforestation.

Recommendation 3.4: policies to encourage modification of reforestation methods to increase carbon sequestration on areas reforested since 1990 should be considered for inclusion in a post-2000 strategy (category 2).

The negotiation of definitions for RAD is key to the relevance of strategies to modify management methods to enhance carbon sequestration on areas reforested since 1990, but this will not be decided until late 2000 at the very earliest. Given the range of possible negotiating results, and uncertainties in the effect of modified reforestation methods on carbon sequestration, estimates of the impact could not be provided. Work should continue on understanding these effects in terms of GHG impacts, as well as costs and policy requirements, in order to allow implementation of modified methods (depending upon negotiation outcomes). Methods to enhance carbon sequestration on areas regenerating after harvest would also be applicable under a managed forest approach.

Recommendation 3.5: policies should be put in place to promote activities in the managed forest which enhance carbon sequestration.

Key impediments include the lack of knowledge on carbon sequestration impacts of specific activities. In the absence of clarity on how the "managed forest" might fit into the Protocol, Canada's emphasis in its initial National Implementation Strategy should be on measures that have a significant long-term, net-positive impact on forest carbon reservoirs, and that are consistent with sustainable forest management practices and other social and environmental objectives.

If the managed forest is negotiated into the Kyoto Protocol, then increases in carbon stocks in the managed forest will be credited in the first and subsequent commitment periods. If it is not, then increased carbon sequestration will still be of benefit because it reduces CO_2 concentrations in the air, although Canada will not obtain a credit in terms of the Protocol. We believe that policies to achieve increased carbon sequestration on the managed forest could have relatively low cost.

3.6.2 Recommendations for Further Work and Studies

Recommendation 3.6: there is a high priority to continue to improve our understanding of the causes, location and extent of deforestation, and ways to reduce its impact.

Analysis for the Table provided what is, to date, the best assessment of deforestation in Canada, although major information gaps remain. Policies to address deforestation from all sources need to be considered, because of the potentially large negative impact of deforestation on CO_2 emissions.

Recommendation 3.7: there is a very high priority to determine the implications for Canada of including the managed forest and storage of carbon in forest products in the Protocol.

Activities on the full managed forest area may be negotiated into the Protocol, and further work is needed to determine the impacts of actions to increase CO_2 sequestration both on site in the managed forests and off site as a result of carbon storage in wood products. The costs of these actions, and the policy changes that would be required to implement these actions, are also important to determine. The potential benefits are thought by some to be much greater than those from reforestation, afforestation and deforestation activities since 1990, which currently are the only forest-related activities included in the Protocol. There is also a very high priority to determine the implications for Canada under various negotiation outcomes related to including the managed forest in the Protocol. In the context of the managed forest approach in the Protocol, Canada should negotiate for a proper accounting of carbon stored in forest products.

Recommendation 3.8: investigate the carbon sequestration and energy-saving impacts of urban forestry.

Urban forestry involves the planting of trees in an urban setting, whether by individuals on their own property or through municipal efforts in parks and along streets. Such planting sequesters carbon and can also reduce energy requirements for air-conditioning and heating. There is uncertainty as to whether this sort of tree planting would qualify as afforestation under the Protocol, an uncertainty that will not be resolved until late 2000 at the earliest. However, urban planting could play an important role in helping to engage Canadians in issues related to climate change, the Kyoto Protocol and the National Implementation Strategy.

Recommendation 3.9: improve information on tree growth and yield, and changes in all carbon pools over time.

The analysis of afforestation, reforestation and activities on the managed forest all suffered from important gaps in information on tree growth and changes in forest carbon pools over time and in response to human activities. In particular, we need to improve information on tree growth and yield, and root, soil and litter carbon changes over time for young stands of trees (e.g. the first 20 to 30 years of growth), intensively managed plantations, and second growth forests, including differences in managed and unmanaged stands. This sort of information is needed for a variety of species and species mixes, as different species and mixes are appropriate for different parts of the country, and for different purposes.

Recommendation 3.10: determine carbon sequestration impact and costs of forest management activities on forest carbon pools over time.

While some analysis of the impact of specific forest management activities on carbon pools have been done, it is clear that more analysis is needed to refine these estimates and determine the extent to which impacts and costs can be generalized, or are site or region specific. More generally, we need to develop a better understanding of the net effect of including the managed forest in the Kyoto Protocol, and determine what are the most cost-effective ways to increase the carbon sequestration of the managed forest while at the same time ensuring sustainable forest management and consideration of other environmental goals. We also need to develop a better understanding of the impact of natural disturbances (naturally occurring fire, pests) on the managed forest.

Recommendation 3.11: improve information on the impact and cost of actions to modify carbon storage of carbon in forest product carbon pools, and their links to on-site carbon storage in all pools over time.

At present, changes in the forest products carbon pool are not included in the Kyoto Protocol and there is also no international agreement on how these changes should be accounted for in national greenhouse gas inventories. We need to better understand how these pools change over time (e.g. the rate of decay of products based on the type of product and type of use), how best to account for the changes, and how to increase the size of the forest products carbon pool — such as through strategies to increase the longevity and durability of forest products and to increase the product substitution using wood-based products instead of non-renewable material with high embodied energy. When looking at how to increase the size of the pool, we also need to consider the related energy impacts that might result from shifts or changes in logging, manufacturing and transportation operations.

Recommendations on measurement, monitoring and verification systems are presented in Chapter 5.

Recommendation 3.12: determine the potential effect of future climate change on predictions of carbon sequestration through activities proposed in recommendations 3.1 to 3.5.

Estimates of sequestration are based on growth curves determined for current climatic conditions. If increases in GHG emissions continue and result in the predicted climate changes over the next 50 years and beyond, the sequestration potential may be significantly overestimated for the later accounting periods. The risk of policies and investments proposed in recommendations 1 to 5 need to be assessed in that respect.

Recommendation 3.13: governments should clearly state ownership policies regarding ownership of carbon sequestered.

Who owns carbon credits on public lands is an issue that will need to be resolved. For example, if a company has a forest management agreement with the province, and invests its own money to increase carbon sequestration, they need to be assured of obtaining the C credit. Lack of clarity with respect to the ownership of carbon credits from sequestration activities (afforestation and reforestation) and from potential future activities that may be included in the Kyoto Protocol or any future agreement, currently constitutes a barrier to action. Further work on ownership issues is needed.

Recommendation 3.14: improve information on the economic incentives needed for afforestation to take place.

4) The level of incentives needed to achieve the targeted level of planting is very uncertain and will have to be investigated more thoroughly as program development occurs — it is the level of incentives that is offered that will have the most impact on the total land afforested. In particular, a relatively ad hoc assumption was used in the analysis of the actions to indicate the scale of the opportunity costs of afforestation.

4. AGRICULTURAL SOILS CATEGORY: CO_2 SEQUESTRATION STRATEGIES

4.1 Domestic Carbon Sequestration in Soils

4.1.1 Analytical Issues and Uncertainties

The National Sinks Table has, in the last seven months, undertaken work on options for monitoring; measuring and verifying changes in soil carbon sinks (Donald, 1999), and is currently working closely with the Agriculture Table to exchange relevant information as the Agriculture Table develops its Option Paper. The Agriculture Table is currently evaluating agroforestry, soil management, nutrient management, shelterbelt, grazing strategies, feeding strategies and forage management options to reduce emissions or sequester carbon. Relevant information will be incorporated as an addendum to the Sinks Option Paper when it becomes available.

This chapter provides a preliminary description and discussion of enhancement strategies which could be implemented to realize the potential of Canadian agricultural soil carbon sinks described in the National Sinks Table Foundation Paper (National Sinks Table, 1998). Strategies cover croplands, pasture management, conversion of marginal croplands to perennial grass, and to a lesser extent, conservation of wetlands riparian areas, which are also addressed in Chapter 6. Section 4.1.2 presents more recent carbon sequestration estimates from the CENTURY model than those outlined in the Foundation Paper. All other estimates of sequestration potential associated with the various strategies are based on expert judgement, as opposed to modeling, and are an elaboration and refinement of the results from Bruce *et al.*, (1998). In particular, refined estimates of the sink potential of croplands have been based on new sequestration rates for reduced/no tillage and reduced summerfallow from McConkey *et al.*, (1999). Major caveats to these estimates are, however, that they are a gross sequestration potential — in that other GHGs need to be factored in the equation — and those lands where management strategies are not applied may still be sources of CO_2 (from conventional tillage, other practices, etc.).

This chapter refers to agricultural soil "strategies" rather than "options." A number of constraints have restricted the Sink Table to a preliminary evaluation of agricultural soil strategies rather than fully developed and analyzed Options. These constraints include:

- The ability to work in a consistent timeframe with the Agriculture Table, whose analysis of options (including soil sequestration) has yet to be completed.

- The need for, and difficulty in, narrowing the range of estimates of agricultural sinks potential. Information from current research efforts in Canada is not yet complete. In some cases, new research needs to be undertaken before estimates can be narrowed with certainty. Timing constraints also limited the availability of experts and contractors to fully analyze the existing and emerging information.

- Differing assumptions used to develop estimates of sink potential. Estimates noted in the Sink Table Foundation Paper vary because of different assumptions related to farmer adoption rates of soil conservation methods, and scaling of estimates by type of agricultural land or by each agricultural activity or practice. These difficulties have not been addressed yet.

- The need to clarify boundaries of interfaces between agricultural soils, shelterbelts, wetlands and afforestation.

The impacts of sequestration practices on possible emissions of other gases (CH_4 and N_2O) have not been assessed by the Table, but should be part of a comprehensive analysis. Current estimates of CH_4 and N_2O emissions from agriculture as reported in Canada's GHG inventory are not sufficiently detailed to enable the attribution and association of emissions with specific agricultural practices. Furthermore, the state of research and knowledge is insufficiently advanced to allow estimates of CH_4 and N_2O emissions associated with conservation practices to be made in a meaningful manner.

Estimates of sink potential have only been provided for the first two commitment periods. The full potential of agricultural sinks may occur over the next 20 to 25 years.

Perhaps the largest uncertainty at this time relates to the outcome of international negotiations on agricultural sinks. If agricultural sinks are not included as an additional activity (Kyoto Article 3.4), then most of the sink potential referred to in this chapter will not help Canada meet its emission reduction targets. At best, we would only benefit from reducing our source of CO_2 from soils. If agricultural sinks are included, another uncertainty arises regarding the rules for measuring, monitoring and verification of changes in soil carbon content.

Measurement of carbon in agricultural soils has been routine for many years, given its importance as a key indicator of soil quality. The key issue with regard to CO_2 sequestration is the certainty of the measurement of a relatively small annual increment of carbon that may be added through sequestration activities. With a well-designed sampling and analysis program, the variability within fields and over time, which can mask small changes in soil carbon, can be overcome (Ellert & Janzen, 1996). A precondition to having the soil carbon sink accepted as a means of reducing or offsetting national greenhouse gas emissions, is the need for a cost-effective way of measuring, monitoring and verifying carbon change in soils, which will be accepted by the international community. The reader should refer to Chapter 5 for a more detailed discussion of the options for a measuring and monitoring framework.

4.1.2 CENTURY Model Results

Soil management practices can lead to an increase or decrease in the organic carbon stored in the soil. This change in soil organic carbon results from an emission of carbon dioxide to the atmosphere or indicates a removal (sink) of carbon dioxide from the atmosphere. Studies of Canadian agricultural soils suggest that while 15 to 30% of the carbon originally present in the surface soil layer has been lost since cultivation, most of this loss occurred in the first two decades of cultivation (Acton and Gregorich, 1995). Smith *et al.*, (1999, submitted) estimated from CENTURY Model predictions that average net annual emissions from cropland in Canada had dropped from 10.1 million tonnes of CO_2 in 1970 to 5.8 million tonnes of CO_2 in 1990. In 1996, net CO_2 emissions from agricultural soils in Canada were estimated to be 1.6 Mt. The primary reason for the reduced net emissions from soils is attributed to the increasingly common practice of conservation tillage. No-till farming was being practiced on over 16% of Canada's annual cropland in 1996, compared with 7% in 1991 (Statistics Canada, Catalogue No. 93-35 and 93-356).

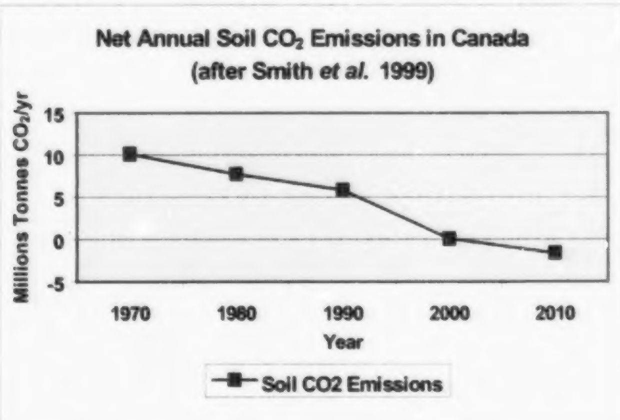


Figure 4.1: Net Soil CO_2 Annual Emissions in Canada
(Source: Smith *et al.*, 1999, submitted)

As shown in Figure 4.1, Smith *et al.*, (1999, submitted) forecast that Canadian agricultural soils will change from a net source of CO_2 to a net sink of 1.6 million tonnes of CO_2 by 2010 if the current trends in farm practices, such as adoption of no till, continue. Soil carbon will not continue to rise indefinitely. The eventual equilibrium carbon content of soils will usually be less that the pre-cultivation content, mainly because soil management practices, even improved, will always disturb the soil through seeding, removal of carbon through harvesting and export from the field.

There is a large degree of uncertainty associated with the estimates provided by the CENTURY model. Comparisons of CENTURY output with field measurements suggest that further refinements would improve the reliability of the model in predicting soil carbon change in response to no-till practices on the prairies (McConkey, 1998). Work is underway to refine and improve the reliability of the model.

4.1.3 Enhancement Strategy – Conservation Practices on Cropland

4.1.3.1 Description

Conservation practices on cropland offer a large opportunity to sequester carbon and consequently enhance the soil carbon sink beyond the baseline forecasts. The C enhancing practices included are: reducing summerfallow; no-till/reduced tillage; use of perennial legumes, pulses and/or forages in rotations; improved crop nutrition through efficient application of fertilizers and organic amendments; and reclaiming wind or water eroded, salinized and other disturbed cropland.

This group of practices offers the largest agricultural potential to sequester carbon in soil during the first and second commitment periods. About 86% of the cropland available to realize this potential is located in the three Prairie provinces. The opportunity noted below is based on new estimates of cropland soil carbon sequestration potential using sequestration rates for reduced/no till and reduced summerfallow from McConkey *et al.*, 1999 for the three Prairie provinces (see Appendix C). Sequestration rates for provinces other than Prairies for reduced/no till is 0.73 Mt CO_2/ha/yr (Bruce *et al.*, 1998). Linear projections of adoption rates based on 1991 and 1996 Census (Statistics Canada, 1997) are also used assuming that existing adoption rates are maintained at least until 2017 (end of the second commitment period). The continuation of past and current trends is judged by the Table to already be challenging, given the various barriers that are discussed in section 4.1.3.3.

There is insufficient detailed information to include estimates for the other practices noted above for this group, although there is room for a greater opportunity once quantification of the effects of their use are included. Further discussion of the carbon impact and the costs are provided in subsection 4.1.3.2.

The Opportunity:

- **18.3 Mt CO_2/yr – first commitment period**
- **18.1 Mt CO_2/yr – second commitment period**

The Challenge:

- **Maintain existing adoption rates for reduced/no-tillage (equivalent to an annual average 2% increase [range 0.5% - 2.8%])**
- **Maintain existing rate of reduction of conventional summerfallow**

Existing Programs

Current adoption strategies vary from province to province. Alberta and Saskatchewan have producer-led programs (ACTS and SSCA) supported by industry, Ducks Unlimited Canada, and provincial and federal governments. Manitoba has a larger number of small producer groups supported by the federal government and Ducks Unlimited (Poole, 1999). It is clear that most of the producers in the "innovators" and "early adopter" groups have made the change to

conservation practices, and that many of the "early majority" (as opposed to late majority) are now considering the change (McKell, 1999).

In B.C., some producer groups are aware of conservation practices and may have received some provincial financial support, however, priorities for extension efforts are currently focussed on other issues (Bertrand, 1999). Ontario has a number of producer groups (soil tillage clubs, soil and crop improvement associations) who are actively promoting conservation practices with provincial government support (Grant, 1999). Ontario government support includes funding for long-term environmental planning for farms. Ontario producers have achieved adoption rates similar to those on the Prairies. In Quebec, with leadership from the provincial ministry, 64 agro-environmental producer clubs have been formed in the last two years to allow "innovators" and "early adopters" to promote best management practices for manure and fertilizer application, soil conservation and agriculture practices, water course programs and reduction of pesticide use. The provincial government funds half of this program and provided the initial framework and train-the-trainer programs (Lapointe, 1999).

The Maritime provinces have a number of local producer-led extension programs supported by their provincial governments (Daigle, 1999). They are focussed on conservation practices for specific crops and land conditions unique to the Maritimes. The Eastern Canada Soil and Water Conservation Centre in New Brunswick was initiated with federal government "seed money" and is focussed on providing information on conservation practices to producers in all the Maritime provinces.

Future Strategies

A future strategy to realize the carbon sequestration opportunity noted above would require commitment nationally to a coordinated and focussed long-term extension program, building on existing programs. The strategy will need to focus on disseminating information to producers to encourage them to adopt one or more of the conservation practices relevant to their cropping needs (face-to-face communication, field demonstrations, use of existing model conservation farms, workshops and media releases). The program will also need to provide technical support for producers who have adopted a practice to ensure that they continue to apply it. More research is also necessary on means to improve the reliability of no-tillage technology.

The program would be most effective in achieving stable, long-term adoption of conservation practices if it is patterned after the provincial or regional alliance-led programs such as those of SSCA and ACTS. Preferably the alliance would include: producer conservation groups; provincial and federal governments; researchers in the field who have the confidence of producers; industry members; and other interested non-government conservation groups.

It will be important to build alliances with existing producer conservation groups, and to ensure that they take a leadership role in delivering information and support to their peers (who are trying to make the decision on whether to adopt conservation practices). It is likely that there will be a need for separate alliances for the Prairies, Ontario, Quebec, the Maritimes and B.C., given the different information needs and cropping practices that they experience. As demonstrated by the current effectiveness of ACTS and SSCA, it would be wise to build alliances around these organizations either provincially or on a regional basis in the Prairie provinces. Similarly, the core of future alliances in Ontario could be with the existing conservation groups, while in the Maritimes, alliances could be built with the existing conservation groups and the Eastern Canada Soil and Water Conservation Centre.

Other measures that would accompany the alliances programs could involve improved research knowledge on the financial benefits of adopting conservation practices, tax concessions on new conservation equipment or cash incentives. The need for cash incentives and tax concessions would be less if commodity prices and general agricultural economic conditions in Canada were improved.

4.1.3.2 Potential Impact on Greenhouse Gases and Costs

Greenhouse Gases

The gross carbon sequestration potential from reduced summerfallow and reduced or no-tillage averages 18.3 and 18.1million tonnes CO_2 per year for the first and second commitment periods respectively. This equates to 0.92 "new" and additional million tonnes of CO_2 per year. The reduced /no-till contribution equates to 15.9 Mt out of 18.3 Mt CO_2 and the reduced summerfallow to 2.4 Mt CO_2. Whether the two impacts can be added is questionable, however, since one land use affects the other. Both practices would need to be treated as an integrated package.

Adoption rates of reduced/no-till from 1991 to 1996 range from 2 to 2.8% per year of cropland in Saskatchewan, Alberta and Ontario. B.C. and P.E.I. achieved intermediate adoption rates of 0.7 to 1.3% while the remaining provinces were at less than 0.5%. Summerfallow is mostly practiced on the Prairies (and to a lesser extent in Ontario). In Alberta and Saskatchewan, the land under conventional summerfallow (mechanical tillage) was reduced by 4.7 to 5.8% per year from 1991 to 1996. Manitoba was the only province to show a small increase (1.6%) in summerfallow during this period (Statistics Canada, 1997). Ideally, longer-term analysis would be needed to follow the dynamics of soil C but it can be anticipated that sequestration will be decreasing to zero as the equilibrium is reached. The amount of tons that we anticipate to be sequestered during the second period is already lower than in the first.

The Agriculture Table is conducting, at the time of writing this report, some CEEMA/CRAM model runs including reduced/no-till scenarios and reduced summerfallow scenarios. Preliminary modeling results for reduced/no till indicate that the annual sequestration potential of 18 Mt CO_2 by 2010 on cropland may be an overestimation. However, there are significant differences in the methods used. An underlying assumption behind the 18 Mt estimate is that croplands that are not under conservation practices are not a source of CO_2, whereas some of them are in fact emitting CO_2. Further differences include adoption rates, how to apply the summerfallow coefficient and how to determine cropping frequencies. An addendum to the Sinks Table Options Paper will be produced in the Fall that will incorporate the modeling results of these sequestration scenarios.

As mentioned in the introductory section, no estimates of reduction or increase in methane or nitrous oxide associated with reduced/no till and reduced summerfallow could be made by the Table at this stage. These practices have been identified as techniques to reduce nitrous oxide emissions on the Prairies and B.C.'s Peace River area (Thomsen Corporation, 1999). More efficient use of nitrogen fertilizers, and the timing of application to minimize the concentration of nitrates in the soil over winter and during spring thaw, have also been highlighted and are being evaluated by the Agriculture Table at this time. However, the impact of conservation tillage is still uncertain. Some studies suggest enhanced N_2O under reduced tillage (to allow the same yield level as with conventional tillage), others suggest lower N_2O emissions under reduced tillage (Janzen, 1999).

Costs

A first approximation of the costs in Alberta from 1993 to 1999, range from \$2.66 to \$6.33 per tonne of CO_2 with a mean of \$4.26 per tonne of CO_2 (Goddard, 1999). These costs include provincial and federal funds to support conservation group programs and applied research on sustainable cropping systems. Estimates in Saskatchewan and Manitoba suggest that direct extension efforts which contributed to adoption rates of 4% to 5% per year range from \$0.60/tonne CO_2 to \$2.00/tonne CO_2 (Poole, 1999) (McKell, 1999). These costs were calculated from direct program costs divided by estimates of adopted hectares given by Poole and McKell, and are unpublished information. These costs do not include provincial or federal support costs for applied research. The costs of the Ontario, Quebec and Maritime programs are unknown.

The overall cost of the future strategy described above, could follow the past experience on the Prairies, recognizing that there may be incremental costs for overall coordination at the national level and for support work within each alliance for existing adopters, but also economies of scale. Based on the mean upper cost of $4.26/tonne CO_2 currently experience on the Prairies and the potential of 0.92 million new tonnes CO_2/yr (see first paragraph above), a rough approximation of the annual cost of the strategy is in the order of $4 million per year.

One way to allocate the costs could be proportional to the land base available for adoption of conservation practices and the potential tonnes of CO_2, which could be sequestered. For example, Saskatchewan has approximately 45% of Canada's cropland, so the cost of an alliance-led extension program could be in the order of $1.8 million per year over the period 2000 to 2017. Another way to allocate the costs could be by the tonne of CO_2 sequestered in the soil.

The cost of this strategy could be partly or fully recoverable in the future if a market develops for carbon offsets in Canada. The costs could also be lower if adequate research efforts are initiated and show clear economic benefits to producers who adopt conservation practices. An example of this is evident in Ontario, where a large percentage of soybean and winter wheat producers have adopted no till to save money with no apparent reductions in crop yields. Corn producers, on the other hand, have not yet adopted no till in a massive way because the risk of low yields is greater (Daynard, 1999).

4.1.3.3 Barriers to Implementation

Almost all of the existing programs are subject to short-term funding (1 to 3 years), with no assurance of ongoing commitment or financial support. Concern about the future of a short-term program detracts from maximizing adoption rates.

(a) A barrier to implementing the above strategy is a lack of federal commitment to the strategy and financial support.

(b) The producers' ability to manage risk is another significant barrier. Conservation practices often require a higher level of management and input costs in the hope of greater returns. As previously mentioned, most of the "innovators" and "early adopters" have already embraced conservation tillage in many provinces — they are able and willing to take the risks and provide the necessary level of management. It will require as much or more effort to convince producers in the "early majority" and "late majority" categories to adopt (Bennett, 1999b). Generally, poor economic conditions will slow adoption rates, as producers are less able to assume the risks and input costs associated with adopting a new method.

(c) It has been suggested that adoption rates amongst the older farmers group are lower. Given that poor economic conditions are affecting more the younger age class of farmers, we might observe a leveling off, or even a slight decrease, of adoption of conservation practices for the next five years or so. Once economic conditions improve, and the younger producers can afford to take over from their predecessors, adoption rates will begin to increase again (Bennett, 1999a) and (Hass, 1999). To take this situation into account, the sequestration opportunity has been estimated using the lower 1991-1996 adoption rates rather than the 4-5% more recently experienced in Saskatchewan and Manitoba.

(d) Uncertainties regarding whether soil carbon sequestration will be recognized internationally as a valid contribution to national reduction targets, as well as uncertainty regarding the ownership of sequestered carbon, are also barriers to some producers and investors.

(e) Policy barriers, such as provincial crop insurance policies, that favour conventional cultivation over reduced tillage are also a barrier.

(f) A disincentive could be the lack of recognition of the efforts of the "innovators" and "early adopters" who have made conservation practices work and convinced others to adopt well before the first commitment period. Some stakeholders share the view that some form of credit for the actions and leadership of "early adopters" would encourage them to participate in helping their neighbours decide to adopt reduced/no-till and less summerfallow in the future.

(g) There is a lack of ongoing research to support conservation methods, to reduce the risks of lower crop yields associated with no tillage, and to provide measurement and verification of soil carbon sequestration. It is vital that there be an ongoing research strategy that complements the adoption strategy for conservation practices. Close linkage of the two strategies is vital to the success of each.

(h) The lack of baseline data for soil carbon levels may prevent farmers from undertaking new practices because they might fear an inability to demonstrate the carbon uptake of their soils and lose the potential economic opportunity.

4.1.4 Enhancement Strategy – Pasture Management

4.1.4.1 Description

This group of practices includes pasture fertilization and intensive grazing management on pastures. Intensive pastures currently cover 4.3 million ha in Canada in tame or seeded pasture (Statistics Canada, 1997). Extensively managed rangeland under continuous grazing is not currently thought to have much potential to sequester additional carbon, but if new management methods on rangeland are found to have potential, these methods could be included in this category in the future.

The Opportunity:

- **0.7 Mt CO_2/yr – first commitment period (0.95 Mha)**
- **1.0 Mt CO_2/yr – second commitment period (1.38 Mha)**

The Challenge:

- **Annual adoption rate of 2% of total area (4.3 Mha), starting at zero in 2000. This equates to 86,000 new hectares per year or 63,000 new tonnes CO_2/yr.**
- **Sequestration rate : 0.73 tCO_2/ha/yr (Bruce *et al.*, 1998)**

Existing programs

Current programs have many similarities between provinces. Most existing programs to encourage improved methods of pasture management are provincial government-led programs, in alliance with local grazing clubs and provincial stockgrower associations (Doris, 1999), (Strankman, 1999), (Adams, 1999) and (Mitchell, 1999). Funding partnerships often include the provincial and federal governments, producer groups, and other parties such as Trout Unlimited Canada and Ducks Unlimited Canada. In Ontario, current adoption strategies include U.S. funding involvement under the joint agreement on the Great Lakes.

Data on adoption rates of intensive pasture management techniques is sparse and often expressed in terms of number of producers who have been influenced by an extension program. In Ontario it is estimated that 25% of producers are managing their pastures intensively, and this has increased from 10-15% in 1990 (Doris, 1999).

In Alberta, a total of 650 producers had taken the Stockman's Range Management Course between 1991 and 1997. Over half reported that they had changed their range management and had improved carrying capacity. Between 32% and 42% reported that they had stabilized forage supplies, restored range condition or improved wildlife habitat. Twenty six percent reported that they had improved the profitability of their operation (Adams, 1999).

Future Strategies

A future strategy to realize the opportunity noted above would require commitment nationally to a coordinated and focussed long-term extension program, building on existing programs. The strategy would need to focus on disseminating information to producers to encourage them to adopt one or more of the pasture management practices relevant to their cattle operations (face-to-face communication, field demonstrations, workshops and media releases). The program will also need to provide technical support for producers who have adopted a practice to ensure that they continue the practice.

The program would be most effective in achieving stable, long-term adoption of conservation practices if it is patterned after the existing alliance-led programs described above. Preferably, the alliances would include producer conservation groups, provincial and federal governments, researchers in the field who have the confidence of producers, industry members and other interested non-government conservation groups.

It will be important to build the alliances with existing producer conservation groups, and to ensure that they take a leadership role in delivering information and support to their peers who are trying to make the decision on whether to adopt conservation practices. It is likely that there will be a need for separate alliances for the Prairies, Ontario, Quebec, the Maritimes and B.C., given the different information needs and pasture management practices that they experience.

4.1.4.2 Impact on Greenhouse Gases and Costs

The net carbon sequestration potential from pasture management averages 0.7 and 1.0 million tonnes CO_2 per year for the first and second commitment periods, respectively. No estimates of reduction or increase in methane or nitrous oxide have been included in the above estimates. Pasture fertilization could contribute nitrous oxide emissions unless applications are carefully timed to avoid excess nitrates in the soil during the winter and spring snowmelt periods. Impacts of a change in grazing management and pasture fertilization on nitrous oxide and on methane from cattle should be assessed.

The only program cost information available at the time of writing is for the highly effective "Cows and Fish" program in Alberta. The program is designed to promote improvement in grazing management on riparian areas along streams and rivers flowing through pastureland. Their strategy has included innovative field demonstrations, face-to-face, and multimedia approaches to delivering an awareness and education program to over 7,000 producers. Their annual cost in 1997 and 1998 was in the order of $200,000 (Adams, 1999).

The overall cost of this strategy is difficult to estimate, given the lack of information on costs of existing programs. Based on applying a "Cows and Fish" type of program in each of the western provinces, Ontario, Quebec, B.C. and the Maritimes, the costs to fully establish the program in all jurisdictions could be in the order of $1.4 million annually. Given the annual adoption rate targets of 86,000 tonnes CO_2 per year, the strategy could cost $20-$22 per tonne CO_2.

As with the Cropland strategy, the allocation of the costs could be proportional to the land base available for adoption of conservation practices and the potential tonnes of CO_2 that could be sequestered. The cost of this strategy could be partly or fully recoverable in the future if a market develops for carbon offsets in Canada.

4.1.4.3 Barriers to Implementation

Most of the barriers cited in 4.1.3.3 also apply to the Pasture Management strategy. Almost all of the existing programs are subject to short-term funding (1 to 3 years), with no assurance of ongoing commitment or financial support (Doris, 1999), (Strankman, 1999) and (Adams, 1999). One can reiterate the lack of research data on the economic benefits of intensive grazing management. Producers are more likely to adopt a new method if there is an economic benefit and short pay back period of one or two years. As well, ongoing research to support grazing management and pasture conservation methods and to provide measurement and verification of soil carbon sequestration is lacking. If research information was able to demonstrate the economic and carbon sequestration benefits of pasture management on extensively managed range, the potential opportunity to sequester carbon in rangeland soil could increase. The unit cost per tonne of CO_2 would also drop accordingly.

4.1.5 Enhancement Strategy – Conversion of Marginal Cropland to Perennial Grass

4.1.5.1 Description

This group includes methods of converting marginal cropland to permanent vegetation cover. It includes land — which was recently converted in the federal Permanent Cover Program ("existing" grassland) — and a similar amount of land, which is anticipated to be converted to grass in the future ("new" grassland).

This group of practices has the potential to sequester up to 2.2 million tonnes of CO_2 per year during the first commitment period, and up to 2.2 million tonnes of CO_2 per year in the second commitment period.

The Opportunity:

- **2.2 Mt CO_2/yr – first commitment period (1.1 Mt from "existing" and 1.1 Mt from "new")**
- **2.2 Mt CO_2/yr – second commitment period (idem)**

The Challenge:

- **Adoption rate of 50,000 ha/year for 10 years from a base of about 500,000 ha of marginal cropland already converted to grass (Bruce *et al.*, 1998). This equates to 128,000 new tonnes CO_2/yr.**

No adoption programs are currently active in Canada. A targeted funding initiative, the Permanent Cover Program (PCP), led by the federal government (PFRA) encouraged Prairie farmers to convert marginal cropland from 1989 to 1993. About 448,000 ha were included in the programs (Ward,1999). The most effective future strategy could be a program similar to the Permanent Cover Program previously offered by PFRA, targeted to marginal cropland only. More analysis is needed on the cost effectiveness of the previous PCP, independently of the impacts of any other program. In other parts of Canada, it has been suggested that poor commodity prices could be sufficient incentive for farmers to convert marginal cropland to permanent cover. There is the potential for competition with eventual afforestation programs which would also target the least economically profitable marginal lands.

4.1.5.2 Impact on Greenhouse Gases and Costs

The sequestration rate on the new grasslands is taken to be 2.94 Mt CO_2/ha/yr for a five-year period (Bruce *et al.*, 1998), after which, the sequestration is taken to be 75% of that amount and equals 2.2 MtCO_2/ha/yr. The ramp-up for converting the lands that has been applied is thought to be very optimistic at 50,000 new hectares converted to intensive management per year as a continuation of past trends under the PCP, and is equivalent to a doubling of the area covered by the original programs.

For the previous programs (1989 to 1993) in all the western provinces, it is estimated that a total of almost 20 million tonnes of carbon will have been sequestered in the soil by 2017 at an overall cost of about $67 million, or $3.35/tonne CO_2 (Ward, 1999). These programs provided farmers with annual financial incentives to convert marginal cropland to grasses and legumes. If a program of similar magnitude is put in place from 2000 to 2010, with similar incentives to maintain the land in permanent cover until at least 2017, an additional 1.1 million tonnes of CO_2 per year could be sequestered during the first and second commitment periods, equivalent to the total carbon sequestered under the existing programs.

A thorough assessment of conversion program should include an analysis of the possible impacts on other GHG gases (CH_4 and N_2O) which could not be done for this paper for the reasons explained at the beginning of section 4.1.

4.1.5.3 Barriers to Implementation

Farmers who participated in the Permanent Cover Program committed their marginal land to permanent cover for 10 or 21 years. Some of this land (committed for 10 years) now has the potential to revert back to cropland.

Current insurance and taxation policies may signal producers to crop as much land as possible. This could also lead to conversion of grass back to cropland and loss of sequestered carbon unless appropriate protection clauses are included in the future contracts, and current policies are modified to provide incentives to producers to participate in a permanent cover program (CCCP, 1999).

Large capital investments in cropping equipment, high debt loads and risk aversion may discourage many farmers from converting marginal cropland to permanent cover.

4.1.6 Enhancement Strategy – Wetland Restoration

4.1.6.1 Description

Based on the discussions at a recent experts workshop (Winnipeg, April, 1999) on carbon sequestration and wetlands, it is evident that while there may be a variety of opportunities to enhance wetlands and sequester carbon, there is very little data to verify and quantify them.

One method that does offer potential is the restoration of margins (riparian zone) around Prairie potholes which have been cultivated for cropland. This opportunity is similar to conversion of marginal cropland to permanent vegetation and could be expected to sequester at least as much as those methods described in section 4.1.5. Ducks Unlimited estimates (Doug Chekay, 1999) that up to one million hectares of riparian zone could be restored on the Prairies (from Bonneau and Townley-Smith, 1999).

The Opportunity:

- **2.9 million tonnes CO_2/yr – first commitment period (1 million ha)**
- **2.9 million tonnes CO_2/yr – second commitment period (1 million ha)**

The Challenge:

- **Adoption rate of 100,000 ha/yr for 10 years. This equates to 290,000 new tonnes CO_2/yr.**

Ducks Unlimited currently supports extension programs on the Prairies to restore wetlands, alone and in partnership with provincial and federal governments and producer groups.

A future alliance modeled after the "Cows and Fish" program (see 4.1.5) and focussed on the riparian zones of previously cultivated prairie potholes, could be most effective in encouraging producers to restore these wetlands. The strategy may have to be supplemented with a targeted funding initiative to provide the producer with economic incentive to adopt.

Restoration of wetlands basins is addressed in Chapter 6; no quantitative estimates of C sequestration are possible at this point.

4.1.6.2 Impact on Greenhouse Gases

Based on an aggressive 10-year plan, 100,000 ha of riparian areas could be restored per year in the Prairies. Up to 2.9 million tonnes of CO_2 per year could be sequestered both in the first and second commitment periods. Methane and N_2O emissions are not included in the calculation. The sequestration rate used is from Bruce *et al.*, (1998) is 2.9 t CO_2/ha/yr, a similar rate that is used for conversion to marginal lands to permanent cover. This estimate is only a rough approximation and should be further studied in conjunction with the revegetation of marginal lands, since this is part of the same landscape — a reality that should be kept in mind. In this respect, the possibility to have some double counting between the two estimates should not be overlooked, but at this level of approximation it is impossible to confirm.

Associated emissions of both N_2O and CH_4 should also be addressed, and until so, the real net effect will remain unknown. As far as costs are concerned, while no specific information is available, one could assume that they would be similar to the revegetation options on marginal lands.

4.1.6.3 Barriers to Implementation

The barriers to the restoration of riparian areas are very similar to others identified under other practices, namely the lack of economic incentive, the loss of convenience in managing large fields, the lack of research information on the benefits to producers and the lack of federal policy to support financial incentives.

4.1.7 Other Considerations

4.1.7.1 Policy Requirements

Federal and provincial government policy support for the above-mentioned strategies will be required for the period 2000 to 2017, assuming we look at a horizon ending at the end of the second commitment period. Policy support would include provision of the necessary funding resources, and leadership through the coordination between regional programs and regular communications of the results at regional and national levels. In addition, existing Canadian agricultural policies should be immediately reviewed to insure that they are compatible with the adoption strategy and not a barrier. These include:

- Neutral crop insurance and taxation policies
- Compatibility with NAFTA and GATT
- Financial incentives as in a permanent cover program

4.1.7.2 Competitiveness, Economic and Social Implications

The key benefits to crop producers in the longer term are greater revenue (and potentially lower input costs resulting from lower fuel use) and more efficient use of fertilizers. This is less certain in Eastern Canada, and more research is required to verify the appropriate conservation methods for producers. Adoption of conservation practices on cropland has resulted in the evolution of new lines of farm machinery, renewed interest in more efficient application of fertilizer, changes in weed control practices, and the use of new and innovative crop rotations.

Beef producers could also achieve potentially greater revenue from higher carrying capacities. The net result of adopting grazing management and pasture fertilization programs to the environment is a healthier, more productive pasture, and soils that are less subject to water erosion. Water quality can be improved by changing management practices to reduce the risk of erosion resulting in improved habitat for wildlife and fish.

The conversion of marginal cropland opportunity may also contribute to the Canadian Agricultural Marketing Council target to double the value of agricultural exports. This would require an increase in livestock production. Increased associated methane and nitrous oxide emissions would need to be assessed.

From an international perspective, the conservation practices and equipment that Canadian producers adopt are transferable to many other countries. The export market for their knowledge and equipment clearly offers future opportunities. In addition, producing food using conservation practices can be used as a marketing tool nationally and internationally by Canadian farmers.

There could be another future economic benefit. If an open system of carbon credits is put in place nationally, the agriculture sector could contribute to emission reductions in other sectors through carbon offsets and trading mechanisms. It will be important for the success of soil conservation strategies that the benefits of carbon sequestration accrue to those storing the carbon — the Canadian farmers.

4.1.7.3 Environment and Health Impacts

The net impact of conservation practices on the environment is a healthier, more productive soil that is less subject to wind or water erosion. The risk of water pollution from erosion and runoff of fertilizer is reduced, and in some areas (such as southern Manitoba) air quality can be improved by the elimination of stubble burning. The overall impact is more sustainable agroecosystems and environment. However, increased no till generally leads to increased herbicide use since tillage plays the role of weed control (Saskatchewan Agriculture and Food, 1999). Further, increased no till and reduced summerfallow may lead to increases in fertilizer use.

For a maximization of the potential co-benefits, and a complete assessment, all these strategies need to be assessed in an integrated manner: wetland; cropland; pasture management; and conversion of marginal cropland.

4.1.7.4 Further Analytical/Study Needs

- Further work is needed to refine the estimates of carbon sequestration, including studies to overcome the constraints noted in section 4.1.1.

- Studies on whole-farm net emission reduction benefits are also needed, including consideration of nitrous oxide and methane emissions, reduction in fuel use and more efficient fertilizer consumption. Whole farm analysis (and whole sector analysis) will come from the Agriculture and Agri-Food Table modeling work.

- In addition, research and development work needs to be broadened and completed for a national soil carbon change measuring, monitoring and verifying protocol as detailed in Chapter 5.

4.1.7.5 Stakeholder Views

Some environmental groups clearly feel that the opportunity for carbon sequestration in agricultural soils has been overstated, and that there will be little if any benefit for farmers. They also believe that there should not be an opportunity to provide the energy sector with carbon offsets, as this would delay or avoid the need for reductions in fossil fuel use.

Some members of the energy sector see soil carbon sequestration as an opportunity to provide them with short-term offsets to help them meet their emission reduction goals. The proportion of offsets in their plans will depend on the costs of internal emission reduction activities and their ability to improve their energy efficiency with their existing technologies. In the longer term (20-40 years), a new generation of more energy efficient technologies may replace the need for offsets to achieve emission reduction targets.

4.1.8 Conclusions and Recommendations

Table 4.1 – Summary of Potential Agricultural Soil Carbon Sequestration Practices

Strategy	Annual Sequestration Rate 2008-2012 Mt CO_2	Annual Sequestration Rate 2013-2017 Mt CO_2	Cost \$/tonne CO_2 range (mean)
1. Conservation Practices on Cropland	18.3	18.1	0.60-6.33 (4.26)
2. Pasture Management	0.7	2.5	8-10 (9)
3. Convert Marginal Cropland to Grass	2.2	2.2	3.35
4. Wetland Restoration	2.9	2.9	N/A
TOTAL	24.1	25.7	

The above Table summarizes the annual sequestration rates associated with each of the four agricultural soil carbon sink enhancement strategies. The cost per ton figures are indicative only and from scattered information. The first enhancement strategy — encouragement of conservation practices on cropland, including reduction in conventional summerfallow offers the most potential in both the first and second commitment periods. Furthermore, it is potentially one of the more cost-effective strategies. The potential offered by this strategy is based on the fact that innovative and early adopting producers have already embraced conservation practices and reduced summerfallow. It should be kept in mind that the potential range on croplands is in fact somewhere between 2 and 18 Mt CO_2 for the first commitment period, given the CENTURY projections for 2010 project a net sink of only 1.6 Mt CO_2 per year assuming continuation of the current practices.

This comment brings the Table to highlight a significant caveat: the sequestration estimates represent only a "gross" sequestration potential. Other croplands that are not subject to conservation practices may well be sources of CO_2 (e.g. conventional tillage, other practices etc.). Other GHGs also need to be factored in the equation (CH_4, N_2O impacts). In that sense, the figures are probably an overestimation of the real sequestration potential, even under the same adoption rates.

While it seems clear that conservation practices on croplands should be undertaken and promoted, it seems premature to recommend their inclusion in the core measures (category 1), given the uncertainties of the negotiations and the need for further assessment. However, the Table believes that incentives to maintain and enhance current adoption of conservation practices (at least in a manner that does not cause discontinuation of existing extension programs or in a "no-regrets" fashion), should be included in the national climate change strategy. Promotion and funding of additional research should also be included in the strategy.

Despite the fact that the strategy is dependent on the outcome of negotiations to refine the Kyoto Protocol, a five-year delay in implementing the strategy with no increase in adoption during that period significantly cuts the potential sequestration rates noted in the above Table. Note, however, that the current adoption rate of reduced/no-till on croplands is not zero.

The second to fourth strategies, including pasture management, converting marginal cropland to perennial grass and wetland restoration, all have significant potential to contribute to the agricultural soil carbon sink. Producers have a more limited track record and additional work is needed to clearly demonstrate both the economic benefits and the carbon changes which could result from implementing these strategies.

Another strategy, shelterbelts planting, such as the continuation of the existing Prairie Farm Rehabilitation Administration (PFRA) program, could bring another 0.4 million tons during the first commitment period. Shelterbelts planting is recommended as a core measure in the afforestation section of this paper.

Recommendation 4.1: conservation practices on cropland, pasture management, conversion of marginal cropland to perennial grass, and wetland restoration strategies should be considered further as potential prospective measures that could play a role in Canada's strategy for reducing greenhouse gases (category 2). Policy development, in particular to build regional or provincial alliances, could commence in 2000.

Recommendation 4.2: all programs that directly or indirectly encourage carbon sequestration in agricultural soils should be maintained. Before existing extension programs are eliminated, they should be audited to determine if they are valuable in sequestering carbon.

Recommendation 4.3: the linkage of the wetland restoration with the conservation practices on cropland, pasture management, conversion of marginal cropland to perennial grass strategies should be taken into account.

Recommendation 4.4: the implementation of the strategies should be on a national basis, recognizing that the available agricultural land base and climate in each province or region will limit the contribution to the soil carbon sink. Program funding could be on the basis of potential for carbon sequestration or number of hectares.

Recommendation 4.5: the federal and provincial governments should review all existing policies, which could affect the soil carbon sink enhancement strategies.

Existing Canadian agricultural policies should be immediately reviewed to insure that they are compatible with the adoption strategy and not a barrier. These include:

- Neutral provincial crop insurance policies and taxation policies
- Compatibility with NAFTA and GATT
- Financial incentives (as in a permanent cover program).

Recommendation 4.6: conduct research on nitrous oxide and methane emissions related to the four strategies noted above. Determine whether there are additional emission reductions or lower net carbon sequestration resulting from the effects of the five strategies on all greenhouse gases. Include fuel use and nutrient management effects.

Recommendation 4.7: determine and refine new equilibrium levels and the carbon sequestration potential resulting from the four strategies.

Recommendation 4.8: conduct research to evaluate the economic benefits of each strategy, and identify practices that best fit each agricultural region of Canada.

Recommendation 4.9: governments should clearly state ownership policies regarding ownership of carbon sequestered in agricultural soils.

4.2 Potential for Soil Carbon Sequestration in Other Countries

4.2.1 Introduction

As seen in the previous section, intensifying best management practices, conservation tillage and restoration of degraded lands could increase the magnitude of carbon (C) sequestration in soils in Canada. This could also apply in other countries, as shown by a study conducted by the Sinks Table (GCSI, 1999), which provides estimates for both global and key countries' soils sink potential. A summary of findings is presented here, and for detailed information the reader should report to GCSI (1999). The Sinks Table felt that an assessment of the situation in other countries could usefully and strategically contribute to Canada's negotiating and lobbying efforts in favour of agricultural soil sinks. The key countries assessed were those with either a large agricultural land base or which are significant players in the climate change negotiations.

Many countries are not yet supportive of the inclusion of agricultural soil sinks in the Kyoto Protocol. This is partly because they are suspicious about the determination of "verifiable changes in soil carbon stocks." Many governments and members of the agricultural communities abroad are also unaware of the potential that exists both globally and in their own country to take actions that, at the same time, improve agricultural productivity and reduce atmospheric CO_2 concentrations. In FCCC negotiations, some countries may be influenced by the global potential and the food security benefits to many developing countries of restoring degraded lands, combating desertification and improving production on cultivated lands. Other countries could be more influenced by their own national opportunities to offset greenhouse gas emissions through soil sinks.

4.2.2 Global Potential

Under current conditions, it is estimated that there is little or no net C sequestration in temperate soils as a whole, and cultivated soils in the tropics are probably a net source of C (Cole *et al.*, 1993; Sauerbeck, 1993). In particular, arable land and pasture use in the tropics currently is thought to contribute a net C flux of 90-230 Mt C (330-840 Mt CO_2) annually (Lal et Logan, 1997).

The range of management practices that can increase soil carbon is described in section 4.1 and is not addressed here. In many cases, these practices go hand in hand and it is not easy to distinguish them. Conservation tillage is worth being mentioned. While it is not exempt of controversy, and its long-term effect on maintenance of soil organic matter levels in tropical and sub-tropical soils is poorly known (Feller and Beare, 1997), one study indicates that estimated increases of reduced tillage on 27-76% of global cultivated areas by 2020 could result in a net increase of soil C of 0.2-0.3 Pg C (730-1100 Mt CO_2) (Cole *et al.*, 1997). Other studies corroborate these findings.

Moreover, soil degradation is of particular relevance to the situation in the developing world. Reliable estimates of soil degradation globally are not available, but one estimate is that there are about 250 Mha of severely degraded lands including about 100 Mha of which would be suitable for croplands (Olderman, 1994). Eighty percent of this severely degraded land is in Africa and Asia. The C sequestration rate for reclaiming such lands is of the order of 0.25 Mg C/ha/yr (Lal *et al.*, 1998). Uncertainty around this estimate is particularly high due to poor data on eroded land area.

On a global basis, the estimates show that a major world-wide initiative, including several practices (such as conservation tillage, elimination of summerfallowing, soil additions, rotations with forages, reversion to grasslands, and restoration of eroded and saline lands) could result in sequestering 0.45 – 0.61 Pg C/yr (1650-2240 Mt CO_2) in the next 20-30 years (Lal and Bruce, 1999). Assumptions behind these estimates are varied and detailed in GCSI (1999); figures should be used carefully since site- and practice-specific data were used to calculate comprehensive estimates.

It is worth noting that the sequestration estimate above is equivalent to about 1/10 of annual CO_2 emissions from fossil fuel combustion and industrial sources, or 1/3 of global emissions due to deforestation and land-use changes, or 1/6 of annual increases in atmospheric CO_2, based on emissions estimates provided in IPCC (1996).

4.2.3 Key Countries' Soil Sink Potential

Opportunities for sequestration differ between temperate and tropical soils because of differences in soil types, climate, farming practices and access to technology. In tropical zones, land-use transition between forest, agriculture and wetlands is continuous. On a country by country basis, the available literature on potential soil C sinks was reviewed for 17 countries, although most information covers only parts of the country or effects of individual measures. In addition, estimates of potential sequestration rates for 29 countries were made on the basis of land-use data, and field-based estimates of soil sequestration for various management practices. Realistic constraints were placed on the likely rates of achievement of conservation tillage, best crop production practices and restoration of degraded lands. Estimates were compared, to the extent possible, with comprehensive published estimates, available only for two countries (Brazil and the U.S.) and the European Union. The calculated values were close to the lower range of the published values and are thus probably conservative. This is, at least in part, because inadequate data were available in the calculated estimates, the effects of measures to reduce erosion on croplands and to include "set-aside" lands.

Table 4.2 – Estimates of CO_2 Sequestration Potential in 2010 in Key Countries and Comparison with Industrial CO_2 Emissions

Key Countries	Estimates of CO_2 Sequestration Potential as Mt CO_2/year (2010)	Industrial CO_2 Emissions Mt CO_2/year (1992) [1]	Proportion of Industrial Emission Potentially Sequestered %
SOUTH AMERICA			
Argentina	65	117	55
Brazil	90 (87-440) [2]	217	41 (40-202) [2]
Chile	11	35	31
Peru	15	22	68
NORTH and CENTRAL AMERICA			
Costa Rica	1.4	3.8	37
Guatemala	3.2	5.7	56
Mexico	48	333	14
U.S.A.	277 (275-760) [2]	4,881	6 (6-15) [2]
Canada	2-24 [3]	468	
AFRICA			
Ethiopia	25	3	830
Kenya	17	5	200
Nigeria	42	97	43
South Africa	37	290	13
ASIA			
China	191	2,668	7
India	182	769	23
Indonesia	41	185	22
Japan	8	1,093	1
Kazakhstan	79	298	27
Thailand	23	112	21
Turkey	36	145	25
SOUTH WEST PACIFIC			
Australia	133	268	50
Fiji	0.3	0.7	43
New Zealand	8	26	31
EUROPE			
Germany	15	878	2
Italy	15	408	4
The Netherlands	2	139	1
Norway	1	60	2
Russian Federation	140	2,103	7
Ukraine	34	611	6
United Kingdom	10	566	2
European Union	(605-770) [2,4]	3,101	(19-25) [2]

[1] World Resources Institute, 1996, except Canada (from Jaques *et al.*, 1997).
[2] Bracketed values are from the published literature.
[3] Sinks Table Section 4.1 Options Paper.
[4] EU estimates include C sequestration potential in trees, biofuel offsets and reduced fuel use with no-till, in addition to sequestration in agricultural soils. The agricultural soil portion is estimated to be about one half of the totals given.

Table 4.2 presents the estimates obtained for potential soil C sequestration annual rates by 2010. Industrial CO_2 emissions per year (1992) are also provided. Underlying them is a number of assumptions on the adoption rates for various practices and regions, including that government policies be put in place that will encourage measures that sequester carbon, (to start in 2000), and that farmers gradually adopt practices to expert judgement plateau levels depending on practices and regions. Overall, the Table feels estimates are above technical and economic feasibility and are theoretical. It should be reinforced that the rates at which practices might be adopted are subject to considerable conjecture. Nonetheless, they provide a good indication of what could be obtained. Projections to 2020 have also been made and are presented in Appendix C for each country. These projections could be readily extended linearly for another decade. Carbon dioxide sequestration in soils, however, has a limitation and soil organic carbon will plateau out after 30 to 50 years.

The countries with the largest absolute potential for C sequestration are, in order, the U.S., China, India, the Russian Federation, Australia and Brazil, all greater than 90Mt CO_2/year. The U.S. potential ranges from 275 to 760 Mt CO_2/yr, mostly from conservation tillage and residue management (Lal *et al.*, 1998). It was found that for most developing countries with relatively low emissions, C sinks could offset from 20% to more than 100% of industrial emissions. For countries with large industrial emissions and large geographical areas, soil C sink potential ranges from 6-15% of emissions. Canada's potential is estimated in this range or just below it. For industrialized countries with small areas, soil C sink potential represents only 1-2 % of emissions, but an increase in "set-aside" lands would add to the potential, especially in Europe. Published estimates for EU as a whole, including potential for set-aside of "surplus" agricultural lands, are much higher (19-25%) (Smith *et al.*, 1998). However, these EU estimates include C sequestration potential in trees, biofuel offsets and reduced fuel use with no-till, in addition to sequestration in agricultural soils. The agricultural soil portion is estimated to be about one half of the totals given.

Constraints imposed on the adoption rates of conservation tillage in developing countries to factor in the economic barriers (maximum 25% of croplands, except in Brazil and Argentina) limit the importance of this factor in all but the largest developing countries (India and China). The use of better fertilization, manuring and other improved management practices, assumes a greater importance in most developing regions. For very large countries with extensive permanent pastures, the potential sequestration by such lands becomes large even though the amount of sequestration per hectare is quite low. This may overestimate the totals for Australia and perhaps Argentina. For individual European countries, figures are probably underestimated (except those for EU as a whole) because data for inclusion of set-aside lands were lacking.

4.2.4 Economic and Environmental Impacts and Barriers

The economic balance of increasing soil organic carbon through a range of management measures could be positive in most countries, even without putting a value on CO_2 reductions. However, a number of critical barriers to adoption must be addressed. They include initial capital purchases of alternative farm machinery and implements, ensuring affordable supplies of fertilizers and/or organic manure, improving irrigation efficiency and aversion of farmers to taking risks on new methods. A paradox is that the greatest capability to pursue C sequestration would be in temperate countries, based on technology availability and the infrastructure to support changes, whereas the greatest need and long-term potential lies in the tropics. Adoption of soil C management approaches in the tropics is further hindered by the gap between benefits to subsistence farmers and the global goal of increasing C sequestration. Emphasis should be put on on-farm benefits, such as increased yields and revenues, as opposed to the global climate benefits.

Whether or not deliberate efforts to sequester more C are undertaken, projected increases in use of N-based fertilizers in developing countries over coming decades will probably result in greater N_2O emissions but also enhanced soil C levels (GCSI, 1999). Moreover, in tropical countries, to the extent that improved management is based on significantly increased fossil fuel consumption, benefits for CO_2 mitigation will be decreased (IPCC, 1996). Further studies are needed to determine the likely net greenhouse gas balance.

On balance, conservation tillage (practiced wisely) has significant environmental "side" benefits. It reduces erosion and water pollutants attached to eroded soil particles, it helps retain soil moisture and reduces farm fuel use. While in some cases farmers have increased chemical inputs with adoption of conservation tillage (herbicide, pesticide, fertilizers), conservation tillage can be practiced effectively. Where best management practices are not followed, however, indiscriminate uses of chemical inputs can lead to adverse environmental side effects. Thus, farm extension and

education programs must accompany programs designed to increase soil carbon sinks. Overall, quantitative estimates of the potential environmental effects are not readily available and further research is needed.

4.2.5 Conclusions

There is a large uncertainty around the estimates presented in this section. More work would be needed to obtain accurate potential sequestration rates in other countries. However, they provide useful information indicating that in seeking to forge an agreement with countries on the inclusion of agricultural soil sinks in the Kyoto protocol, a three-fold strategy could be followed:

1. For large emitting countries with small land areas and small C sequestration potential, emphasis should be placed on the multiple benefits of promoting a major global program to restore degraded lands and vigorously practice conservation measures on cropland.
2. For developing countries, and for large emitters with large soil sink potential (e.g. U.S.A., Russian Federation, China, India), the benefits to the individual countries of C sink offsets could be stressed.
3. In Europe, while some individual countries have small soil sink potentials, as noted above, published estimates for EU as a whole are substantial and could well influence their negotiating position. Countries with small land mass but with strategic connections to Canada, such as the United Kingdom and the Netherlands, could be supportive. Both of these countries are actually showing the most interest and openmindedness in the negotiations of all the EU countries.

Further, the Clean Development Mechanism, Joint Implementation and International Emissions Trading under the Kyoto Protocol, may provide opportunities for assisting developing countries and the farm community. This could help farmers to institute management practices which result in increasing levels of soil organic carbon and less atmospheric CO_2, along with greater crop productivity and other environmental benefits.

5. MEASUREMENT, MONITORING AND VERIFICATION OF CHANGES IN CARBON STOCKS

5.1 Background and General Considerations on Science Needs

Article 3 of the Kyoto Protocol emphasizes that national reports on sources and removals by sinks of greenhouse gases resulting from human-induced, land-use change and forestry activities must be transparent and verifiable, using modalities, rules and guidelines yet to be decided upon. Efforts to gain acceptance of other potential sinks, such as the managed forest and carbon in agricultural soils, will be dependent on the availability of such credible data.

Current data and understanding of carbon flux processes are as yet inadequate to provide a credible reporting system. For example:

- national inventories of carbon stocks in forests ecosystems, in agricultural soils and in wetlands, as well as the understanding of the interactions between diverse systems, are inadequate to provide a baseline against which to measure change.
- there remain some important uncertainties as to how physical and chemical processes within land ecosystems, and particularly soils, take up carbon dioxide from the atmosphere, transfer it as carbon compounds within the ecosystems and retain it within the system as a carbon reservoir or release it again into the atmosphere. These processes vary significantly from one location to another and with time. They are also sensitive to anticipated changes in environmental conditions such as temperature and precipitation, atmospheric concentrations of carbon dioxide and acidic deposition.
- there is a poor understanding of how the carbon stock in the total carbon system changes, particularly in below ground, dead organic and dissolved organic carbon pools within ground and surface water.
- improvements are needed in techniques for confidently scaling up data on changes in carbon stock in highly variable ecosystems from the process level to ecosystem, landscape and national scales.

To appropriately address these concerns, a number of data and research needs must be addressed. Many are specific to the forest, agriculture and wetland ecosystems, and are discussed in greater detail in sections 5.2 and 5.3, and in Chapter 6, respectively. However, there are a number of generic needs that are applicable to all activities currently included under the Protocol or that may subsequently be approved for inclusion. These are as follows:

5.1.1 Common Data and Inventory Needs

Key priorities include:

- **Baseline Information.** There is an urgent need to maintain, enhance and develop databases of soils, wetlands, climate, land cover and management practices.
- **Monitoring systems for detecting change**. Well-designed and long-term benchmark monitoring and assessment systems can overcome ecosystem carbon variability. For some areas of research, particularly wetlands, coordination mechanisms need to be established to provide leadership and focus.
- **Scaling systems**. Better use needs to be made of existing data bases to link carbon flux processes to larger scale variables such as forest stand type and age classification, wetland classification, soil hydrology regimes, land-use practice, etc.
- **International peer review process**. Data collection and monitoring systems must be credible and verifiable if estimates of carbon sequestration are to be acceptable to the international community.
- **Data Management**. An integrating framework and data storage system needs to be developed to accommodate and combine the diverse sorts of data that will emerge from diverse baseline monitoring programs.

5.1.2 Research Priorities for Processes that Control Carbon Sequestration

While numerous empirical models for estimating growth and yield of forest and agricultural ecosystems already exist in Canada, these are inadequate for estimating the rates of long-term accumulation and retention of carbon in these ecosystems, particularly for below-ground and dead biomass pools. They are also unable to model the impact of changes in environmental factors that are important influences on ecological carbon flux processes but may not have occurred during the collection of data for such empirical models. To do so requires process based models that require a good understanding of natural geo-biophysical processes within ecosystems.

A number of relevant workshops and meetings have recently attempted to articulate some of these concerns. In May, 1998, for example, the Soil and Water Conservation Society held a meeting of stakeholders and experts in Calgary to, among other activities, develop research priorities for estimating the effects of soil conservation on carbon sinks. During early 1999, various technical meetings of experts were held in Toronto, Vancouver and Oak Hammock to identify research priorities related to below-ground greenhouse gas flux processes, identifying options for forest carbon sink reporting, and assessing the potential role of wetland systems in carbon sequestration (Hengeveld and Beaulieu, 1999; Kurz 1999).

The following are some of the key generic research priorities that have been highlighted by those meetings and other related discussions:

- improved understanding of soil composition, and of decomposition processes, including aerobic vs. anaerobic and autotrophic vs. heterotrophic processes, in Canada's forests, agricultural sector and wetlands;
- improved understanding of response of carbon fluxes and storage to management practices, to global and regional environmental change, including climate change and carbon dioxide and nitrogen inputs, and to disturbances such as fire, insects, floods and droughts;
- carbon budget model development and evaluation. Such models will be essential in applying the results of related carbon flux process research to the development of credible and verifiable estimates of carbon sinks;
- research and evaluation of the process of scaling up data and model output from the process to ecosystem and landscape scales; and
- the impact of changes in carbon storage on nitrous oxide and methane fluxes.

5.2 Measurement, Monitoring and Verification of Forest Carbon Stocks

5.2.1 Data Needs

The Sinks Table commissioned a study to assess the options to meet the requirements for verifiable reporting of changes in carbon stocks from reforestation, afforestation and deforestation, and other potential forestry activities in Canada. The report (Kurz, 1999), based on an expert workshop held in January, 1999, in Vancouver, reviews the data needs resulting from the reporting requirements, discusses some of the available methods to obtain these data, and then outlines the design and features of a national C reporting system.

The reporting requirements under the Kyoto Protocol and the UNFCCC establish a need for a national-scale reporting system that provides information on the following indicators:

1. for reforestation, afforestation, deforestation and any other activities that may subsequently be approved:
   - i) the area affected by each activity since 1990, and
   - ii) either:
     - a) the C stock (including above-ground biomass, below-ground biomass and soil C)
       on this area at the beginning and at the end of each commitment period; or
     - b) the rate of change in C stock (including above-ground biomass, below-ground biomass and soil C) on this area during each commitment period.

2. the C stocks in 1990 and estimates of changes in subsequent years.
3. the annual anthropogenic greenhouse gas emissions by sources and removals by sinks from land-use change and forestry in the "managed" forest.

Requirements 1 and 2 result from the Kyoto Protocol (Articles 3.3. and 3.4). Requirement 3 results from the FCCC and is not altered by the Kyoto Protocol. Because of the growing international scientific interest in the role of boreal forest ecosystems in the global C cycle, the reporting system should also be able to deliver information about the C stock changes in the total forest area of Canada.

As mentioned in Chapters 2 and 3, the exact definitions of reforestation, afforestation and deforestation (RAD) activities under the Kyoto Protocol have not been negotiated. The outcome of the negotiations will have a large impact on the area of the so-called "Kyoto Forest." It is comprised of the area on which those direct human activities have occurred since 1990 that will establish a requirement to report the C stock change during the five-year commitment periods, starting in 2008. It can be anticipated that both afforestation and deforestation activities will be reported under the Protocol. Uncertainty remains, however, about the definition of reforestation, which may either include or exclude the establishment of a forest following harvest. In Canada, about 1,000,000 ha are harvested annually; and including reforestation following harvesting, would therefore result in a much larger area with reporting requirements under the Kyoto Protocol. Note that the Kyoto Forest will include some areas that have been deforested since 1990 and may now be in a different land-use category. Observations on changes in forest cover must be supplemented by information on the cause of the observed change in order to determine whether the area will be included in the Kyoto Forest. The data needs for reporting of C stock changes will also be affected by the negotiated additional direct human-induced activities under Article 3.4.

Finally, negotiated definition of the C pools that will be included in the reporting under the Kyoto Protocol will also impact on data requirements. The data needs, and the difficulty of obtaining the data, increase from above-ground biomass, to below-ground biomass, to dead organic matter pools.

The UNFCCC calls for reporting of net C fluxes in the "managed" forest of Canada. This area will include most, but not all of the area of the Kyoto Forest. The extent of the managed forest in Canada depends on the choice of definitions and ranges from 146 million ha for the non-reserved accessed timber productive forest to 245 million ha for the timber productive forest (Lowe *et al.*, 1994). Within the managed forest, all changes in forest C stocks will be reported, regardless of the cause of the change. While there is no direct reference to "verification" of the reported C stock changes, reported estimates should be scientifically credible.

The minimum requirement of a national C accounting and reporting system is to track, store and report information on past changes in C stocks for three areas: the Kyoto Forest, the managed forest and the total forest area. Furthermore, a national C accounting system should:

- be scientifically credible;
- meet the reporting requirements of both the Kyoto Protocol and the FCCC;
- provide the key indicators of C stock changes in annual time steps and for each commitment period, as required by the reporting guidelines;
- be based on methods that allow scaling of information to the national level;
- provide estimates that are internally consistent across the various spatial entities for which reporting may occur;
- keep a spatially explicit record of the location of activities that have resulted in the creation of the Kyoto Forest;
- calculate the C stock changes either by keeping a record of the C stock in the Kyoto Forest at the beginning and end of each commitment period or by estimating the C stock change during the commitment period using the "flow method;"
- estimate the C stock at the beginning of a commitment period in areas in which RAD activity occurred during the commitment period;

- estimate C stock changes in all pools included by the Kyoto Protocol (i.e. one or more of above-ground biomass, below-ground biomass and soil C);
- be verifiable;
- adapt to the evolving definitions, accounting procedures and methodological guidelines;
- be operational before the first commitment period starts;
- be cost efficient;
- provide estimates of uncertainty;
- be able to provide projections of future C stock changes based on various scenario assumptions (optional); and
- be able to assess consequences of alternative definitions of RAD and other forest management activities on the reported C stock changes (optional).

5.2.2 The Main Components of a National Forest C Measurement, Monitoring and Verification System

The information system will be comprised of several components, each of which will fulfill specific functions. The main functions, as presented in Figure 5.1, are data acquisition, data storage, models, parameter databases, reporting tools and verification.

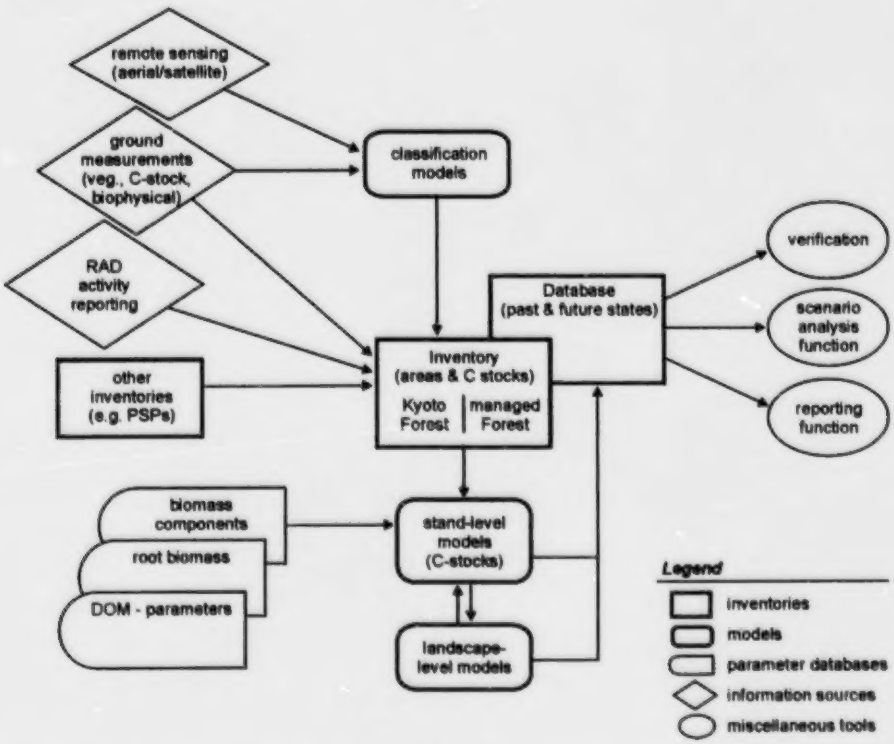


Figure 5.1 The Main Components of a Forest National C Accounting System

Several options are available to provide some of these functions. The details of the reporting requirements depend heavily on the unknown outcome of future negotiations on the implementation of the Kyoto Protocol, which will determine the extent of the Kyoto Forest, the types of activities and the C pools that need to be tracked. Hence, there is at present no single best option. The suggested approach instead is to build an overall framework that will enable the use of the appropriate tools for each function. The most important role of the overall information system will be to provide the structure, standards and interfaces to integrate the information flow between the various components.

Data acquisition

Six options have been identified for the acquisition of data on the area of the Kyoto Forest and on the C stock and C stock changes in the Kyoto Forest, the managed forest or the total forest area. These are remote sensing based on comprehensive coverage, remote sensing based on a statistical subsample, determination of change in inventories, activity reporting, ground measurement of C stocks and ground measurement of C fluxes. The relative contribution of each method to meeting the national reporting requirements will depend on the choice of definitions for the Kyoto Protocol and on which reporting requirement is to be met. In all cases, a mixture of methods will likely be applied, and the most important contribution of the national reporting system will be the integrating framework that can accommodate and combine data from the various sources.

Data Storage

Two data storage functions are required for the national reporting system. The first database contains the compilation of relevant inventory information, from a variety of sources. It includes information on the location and the area of the Kyoto Forest created from reforestation, afforestation and deforestation activities since 1990. The second database contains derived inventory information on the C stocks of these areas, computed from models that extrapolate measurements in space and time. Both databases should be spatially referenced.

Models

Four types of models will potentially be required for the reporting system:

- models for the extrapolation of measurements of volume or C stocks in space,
- growth and yield models to project volume dynamics over time,
- ecosystem C dynamics models with which to project above- and below-ground biomass and dead organic matter pools of individual ecosystems, and
- landscape-level C dynamics that project the age-class distribution and dynamics of many ecosystems.

Some of these models could be nested (i.e. the ecosystem dynamics model could make use of a growth and yield model to drive stand volume projections) and the landscape-level model could incorporate the ecosystem-level C dynamics model.

There are dozens of growth and yield models in Canada. Most of these models are maintained by provincial agencies and industry for timber management and planning. These models are calibrated to the species, site and ecological conditions of the region in which they are applied. Generally, such models project stand volume information over time, and many of them are designed to operate with the inventory format used by an agency or forest company. The choice of which growth and yield models to use for the national reporting system will depend on the regional circumstances and the available models. The role of the national reporting system will be to provide the standardized inventory information that will permit the use of regionally calibrated growth models for the projection of stand volume.

Ecosystem dynamics models predict changes in all ecosystem C pools, including above- and below-ground biomass and dead organic matter pools, such as litter, coarse woody debris and soil organic matter. The two main purposes of these models are to predict the dynamics of all biomass components (not just stem volume) and to link changes in dead organic matter pools to stand dynamics, management impacts and disturbances.

Ecosystem models are typically research tools that are not used in operational forest management. These models can be driven either by empirical growth equations (i.e. a growth and yield model) or through the simulation of biological

processes. The former approach benefits from the large amount of growth and yield research that has been conducted in Canada, and from the very large number of measurements from permanent sample plots. The limitation of empirical growth models is that they are not responsive to global change. A simulation approach based on process modeling, however, will be more difficult to calibrate to regional and site-specific conditions, but may be designed to account for the impacts of global change on C dynamics.

Landscape-level C dynamics models are required to integrate the changes in C stocks over a larger area. These models calculate changes in C stocks from the area and C stock information of individual stands, and from the age-class distribution of the stands in the landscape. Operational forest management often employs landscape-level models of stand volume dynamics for planning of harvest schedules or other management activities. For the analysis of C dynamics, the indicators generated by such models need to be expanded to include C stocks in all ecosystem C pools.

The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2, Kurz *et al.*, 1992; Kurz and Apps, 1999) is a landscape-level C dynamics model that has been applied to analyses at various spatial scales. Landscape-level models that provide similar functions are required to operate with the information that will be contained in the inventory of the Kyoto Forest, or with inventories of the managed or the total forest area.

Parameter Databases

One important contribution of a national C reporting system can be to develop and maintain databases with parameters, methods and other information that will be required for all analyses of forest ecosystem C dynamics. The reporting requirements of C stock changes will result in an increased need for parameters and methods with which to expand the readily available information on stem volume dynamics to other ecosystem C pools. Thus numerous analysts in resource management agencies, forest industry and research organizations will be facing the same challenges, and will embark on reviews of a limited number of research studies. The nationally coordinated development of methods and parameter databases will greatly increase the credibility of the models that will be required to develop verifiable estimates of C stock changes, and it will facilitate the verification of the reported results.

Parameters and methods are required for converting stem volume to other above-ground biomass components, for calculating below-ground root biomass, and for initializing and simulating dead organic matter pools.

Reporting Tools

The reporting tools required for the national reporting system must be able to query and summarize the information contained in the database of projected C stock estimates. These tools must be able to report C stock changes for various areas such as a region, province, the Kyoto Forest, the managed forest or the total forest area of Canada. Ideally, the tools should also be able to incorporate the various evolving definitions and accounting methods of the Kyoto Protocol, thus permitting an analysis of the consequences of selecting specific definitions.

The important contribution of a nationally coordinated approach will be to ensure that the methods used for accounting C stock changes are consistently applied and are in agreement with the international protocols. This will also facilitate verification of the reported results.

Verification

Two separate aspects of reported C stock changes could be verified: the reported values with their underlying component estimates of area and C stocks; and the system that was used to derive these estimates. At present, the term "verifiable estimates" used in Article 3.3 of the Kyoto Protocol is not specified further, and either or both of these aspects may have to be verified in the future. The decision about the required verification process may be the outcome of future negotiations on the implementation of the Kyoto Protocol. The national C reporting system can contribute significantly to the verification process by providing peer-reviewed data acquisition, models, parameter sets and reporting methods. The system should also provide a mechanism for model comparison, evaluation and peer review. It may even be appropriate to consider the concept of certification of models and methods that may be employed to operate on the primary information contained in the central inventory. Only results obtained from such approved models will then be accepted in the database of projected C stocks.

Summary of Options for Various Reporting Requirements

Various combinations of spatial scales, reporting protocols and ecosystem C pools result in a potentially large number of different reporting requirements. These can be met with a system that provides the functional components discussed above. Several functional components can be provided through multiple options. The various reporting requirements primarily affect the way in which the area data will be acquired and the choice of tools to represent ecosystem C dynamics. In all cases, an overall framework is required to store, analyze and report the C stock information. Examples of how the options change with the reporting requirements are discussed in the report.

The choice of the specific methods used to provide each of the functions and their relative importance will be affected by future definitions for the implementation of the Kyoto Protocol. For example, if RAD activities are limited to afforestation and deforestation, but exclude reforestation following harvest, the total area of the Kyoto Forest would be small. The most effective method for the acquisition of area estimates may be an activity-reporting system that tracks all afforestation and deforestation activities (although it would be difficult to obtain data from 1990 to the year in which the system is implemented). For the reporting of C stock changes in the total forest area of Canada, data acquisition on the area and age-class distribution of the various forest ecosystem types would best be accomplished through a remote sensing approach, based either on comprehensive coverage or a statistical sample of the area.

Central to the overall national C reporting system will be an inventory containing data on the last observed state of the area. The spatial extent of this inventory could be only the Kyoto Forest the managed forest or the entire forest area of Canada. While the size of the inventory would vary considerably, for the purpose of this general discussion, in each case the inventory fulfills the same functional role, namely to store information obtained from measurements.

Associated with this inventory should be a database system that contains information on past (e.g. 1990), current and future states of the area included in the inventory. The database will contain, for each area in the inventory, the estimated size of each C pool at various points in time. This information will be extrapolated in time and in space using stand- and landscape-level models of ecosystem C dynamics. The results contained in the database can then be summarized and presented with the reporting tool.

Deforestation Monitoring Pilot Project

As listed in the recommendations below, one of the needs is the development and testing of methods for land-use change detection via remote sensing. The Sinks Table is commissioning a study over the course of 1999 to 2000 to the Canadian Forest Service, in Victoria, B.C. that will develop a model system design using the National Forest Inventory, remote sensing and other data sources to address the verifiable measurement of changes in carbon stocks due to deforestation for Kyoto Protocol reporting. The study will address the first phase of three aimed at defining the system and also address the key issues. Later phases would need to test, refine and implement the model.

5.2.3 Research Priorities for Forest Models Used in Reporting

As noted in section 5.2.2, accounting for changes in forest carbon stocks due to measures undertaken to address Kyoto targets requires the development of reliable carbon dynamics models, both at the ecosystem and landscape levels. Related research needs to enhance the reliability and confidence in such models, and deal with all scales of the forest ecosystem— from the stand level through landscape scales to biome or national scales. Priorities at the carbon flux process level include:

- improved methods for parameterization and quantification of CO_2 efflux from soils and roots by stand type and stand age at daily, seasonal, annual scales, across climatic regions, as affected by weather and climate;
- improving the parameterization of above-ground/below-ground C and N allocation patterns, as affected by climate change, and nutrient regime, by stand/site type and stand age; and
- improved measurements of the decay of wood residues on site 0 to 10 years after harvest. This is a major determinant of when a regenerating forest can become a sink.

At the landscape level, C and N build up in accordance to position of each soil/forest site type with respect to terrain, lateral hydrological flow regime, soil substrate, vegetation type and surrounding disturbance pattern. These relationships need to be understood and characterized in terms of Net Primary Productivity (NPP), Net Ecosystem Productivity (NEP) and Net Biological Productivity (NBP). Such research requires:

- spatially explicit, high-resolution analysis of existing databases such as digital elevation maps, ecological site classification maps, forest inventory information, geology and soil maps (CANSIS +), wetland, stream and road maps, satellite imageries, etc;
- evaluating the temporal and spatial variations of the hydrology regime and related landscape-level processes and feed-back loops regarding C and N stocks and fluxes, to determine the interactions between hydrological flows and the size of C and N pools/fluxes;
- developing scaling techniques appropriate for parameterizing and quantifying C and N stocks and flux dynamics from stand to landscape level, and from the landscape- level to the biome level; and
- using landscape-level measurement/monitoring tools to validate landscape-level C and N stock/flux models.

Working at the biome/national level requires a national integration of existing modeling procedures and relevant databases. There are national scale maps already available for NPP and NEP. Part of the challenge is the linking national forest inventories with provincial/industrial inventories and other relevant databases, to allow for an accurate field operational interpretation of C stocks and fluxes. Relevant research priorities include:

- obtaining additional data to validate the performance of biome-level C stock/flux models in estimating NPP, NEP and NBP under changing climate conditions, particularly that of CO_2 concentrations. Special databases generated via Ameriflux, Fluxnet (international networks of ecosystem CO_2 and water vapour flux monitoring stations), FACE experiments and BOREAS are important sources for such data, but their value would be greatly enhanced by complementary information regarding soil, hydrology and tree physiology; and
- developing and using numerical enhancement procedures for projecting and interpolating climate/weather conditions from existing weather records (actual or modeled) across the country and for as long a period as feasible.

5.2.4 Conclusions, Recommendations and Next Steps

In concluding, the Table felt that a national system for measurement and reporting of C stock changes in Canada should:

- be a modular system whose primary role is to provide the framework for data compilation, synthesis and analysis;
- provide a central data storage facility that compiles primary inventory information;
- provide the database structure to store the projected values of C stock estimates for past and future years;
- built upon the large body of data and knowledge developed for the purpose of forest management, including forest inventories, growth and yield models, and landscape-level planning models;
- develop and maintain methods and databases required for analyses of C stock changes, including biomass expansion factors, root biomass estimation and dead organic matter dynamics;
- develop and maintain stand- and landscape-level C dynamics models with which to estimate C stock changes for the areas included in the primary inventory, including the C dynamics affected by natural and human disturbances and climate change; and
- coordinate the process and research required to improve and enhance the available data and models required for C stock reporting.

Recommendation 5.1: A steering committee composed of governments' representatives and stakeholders should be established and provided with adequate commitment and funding, to take responsibility for carrying through with implementing the forest C accounting system. Such a committee should ensure that the reporting system employs methods and models that are meeting the requirements of the verification process, once defined by the international negotiations.

One very important role of the steering committee for the national C reporting system should be the coordination and synthesis of ongoing activities, data collection and the development of information systems.

The following outlines a number of key studies and tasks which should be undertaken as a follow up in order to fulfil Canada's measurement, monitoring and reporting needs:

- Systems analysis should be used to identify the data components that contribute the largest uncertainty to total C flux due to RAD activities in order to determine priorities for data, research and methodological development (e.g. which RAD activities require closest monitoring, which C pools require most refined estimates).

- Based on the results of this prioritization exercise, a spatially referenced Kyoto Forest tracking system should be established. The sooner this is started, the less reconstruction of past conditions and events that occurred since 1990 will be required.

- It should be recognized that the NFI will meet some needs of the reporting requirements but clearly not all. There is potential to significantly increase the NFI utility through design modifications:

  i) include information on coarse woody debris and soil C;
  ii) increase sampling density and re-measurement frequency in focal areas (i.e. in areas with high RAD activities); and
  iii) formalize the relationship between the NFI and the C measurement and reporting system.

- A spatially explicit accounting framework should be built that can be applied consistently across the country and can work with various data formats (i.e. provinces or forest companies can apply it and populate it with their own data). It should be ensured it is supported and documented, and allows a national roll-up of the results.

- Methods for land-use change detection via remote sensing should be developed, tested and demonstrated.

- Data on litterfall and other large plant residue inputs to dead organic matter pools on permanent sample plots should be collected and compiled. Data on decay rates in various ecosystem types across Canada should be developed and compiled. Link should be maintained between litter/dead organic matter parameter databases and the national C accounting system.

- Special attention should be given to the impacts of stand history on the size of dead organic matter pools, which will differ greatly between stands that were previously affected by logging and those affected by wildfire or insects. Methods and inventory information need to be developed that assist in the determination of stand history and the resulting amounts of dead organic matter pools in forest ecosystems across Canada.

- The national C reporting system can most effectively be developed if it seeks to build upon the large body of scientific knowledge developed in the Canadian growth and yield modeling community. While it is recognized that most growth and yield models have limited capability to respond to the changes in growing conditions from global change, they do provide the synthesis of a large number of actual measurements of stand conditions and their change over time from ecosystems across all of Canada.

- To address the issues of global change, some of the ecosystem dynamics models employed in the analyses of C stock changes should be process models that simulate ecosystem dynamics based on site and climate conditions.

- One or more landscape-level C dynamics models should be required to integrate the C dynamics of a large number of ecosystems, as these are affected by growth, natural disturbances and forest management activities.

- The Carbon Budget Model of the Canadian Forest Sector can be used for sensitivity analyses to determine priority research needs and to conduct preliminary analyses of past and future C stocks in Canada's forest ecosystems.

5.3 Agriculture Soil Carbon Stocks

5.3.1 Introduction

The acceptance of agricultural soils as a carbon sink within the Kyoto Protocol is contingent upon the development of a verifiable measurement and monitoring framework to enable a precise determination of net changes in carbon storage in agricultural soils. Indeed, if soils are included in the Protocol, what will most likely be needed is an estimate of the change in C stocks in soils between 2008 and 2012.

Moreover, reporting to the Framework Convention, as per the IPCC Guidelines for National Greenhouse Gas Inventories, requires that annual estimates of CO_2 fluxes be determined for agricultural soils. As part of its annual greenhouse gas emissions and removals inventory, Canada has been reporting CENTURY results (Neitzert *et al.*, 1999, in press). A measurement and monitoring framework based on documented land use systems and accurate estimates of soil C stocks will enable a more precise determination of net changes in C storage in soils than put forward for the FCCC reporting.

The main challenges in developing a verifiable and transparent system for estimating agricultural soil carbon dioxide emissions and removals include: the inherent high variability in soil carbon; uncertainty as to how land use changes affect soil carbon levels; and the difficulties associated with scaling up of local estimates of carbon sequestration to national estimates.

Saskatchewan is host of a pilot project of a system for quantifying and verifying changes in soil C stocks due to adoption of a no-tillage system in which a group of no-tillage farmers, in conjunction with a team of scientists, are involved. The method, involving measuring soil C change on the same small benchmark over time over a network of 150 benchmarked fields, was designed to try to minimize the variability of soil C (McConkey and Lindwall, 1999).

5.3.2 Options for a National Measurement, Monitoring and Verification System

The Sinks Table commissioned a study that assessed the components of a monitoring, measurement and verification system of changes in soil carbon stocks (Jacques Whitford and University of Saskatchewan, 1999). The main elements of a monitoring and measurement framework to arrive at verifiable estimates of changes in soil carbon are shown in Figure 5.2. The measuring and monitoring framework consists of four major elements: predictive tools; land-use and management data; soil/climate database; and scaling-up techniques. Within each of these elements, several options were evaluated and are summarized below.

5.3.2.1 Summary of Options

Predictive Tools

Soil organic matter (SOM) models and other predictive tools embody our best understanding of soil carbon dynamics. In terms of a framework for estimating and verifying management-induced changes in carbon stocks in agricultural soils, predictive tools provide point or plot-scale estimates under climates and soil types where no direct field measurements exist. These models can be used to extrapolate SOC change for various management practices into the future. Options for predictive tools are:

- CENTURY SOM Model
- A complex process model of plant-soil-nutrient cycling which has been used to simulate carbon and nutrient dynamics for different ecosystems.
- Other Process Models
- There are as many other models of varying degrees of complexity ranging from simple empirical models to more complex process-based models. Examples include DAISY, ROTHC, DNDC and CANDY.
- Rule-based System

- Rule-based systems have been used extensively in many agricultural applications, and consist of a series of rules and conditions which lead to a prediction of changes in SOC for combinations of land use, soils and climate.
- Complementary Model
- A combination of the functions of a process model and a rule-based system.

Land Use and Management Data

Land-use and management data provide estimates of changes in agricultural management practices which, when linked to a soil and climate database, provide the input data required by the predictive tools to make accurate estimates of the change in soil carbon stocks. Land use and management data could be obtained from a variety of sources:

- Statistics Canada census data
  Every five years, Statistics Canada, through its Agricultural Census, collects a variety of data related to agricultural land use. The main census parameters of interest for C sequestration are: total farm area; data on areas in conventional, conservation and zero tillage; major crops grown; and area in summerfallow, pasture and other farm land.
- Provincial and municipal agricultural statistics
  In some jurisdictions, land-use and management statistics are collected by provincial and municipal governments. Where they exist, provincial land-use data could be used for estimating land-use changes over the commitment period.
- Provincial crop insurance data
  Provincial crop insurance agencies collect a limited amount of agricultural statistics for the areas which they insure. Useful provincial crop insurance data would include cultivated area and crop grown.
- Remote sensing
  Remote sensing tools such as LandSat TM imagery could be used to measure changes in land-use during the commitment period. This would involve an analysis of LandSat imagery at the beginning and end of the commitment period.
- Field scouting
  Data on land-use management could be obtained through a field scouting program, which would be designed to measure changes in land-use management on the basis of a representative sample of farms for each major agricultural region in the country.
- Direct Reporting
  Information on land use and management may be obtained through a system where farmers report changes in land use management. This would likely occur only if it were part of a system of carbon credit trading at the farm level.

Soil/Climate Data

Regional soils and climate data will form an integral part of any framework to measure, monitor and verify changes in soil carbon stocks. These data will be used to calculate current SOC stocks and to provide input variables for model simulations. The options for soil/climate data are:

- Soil Landscapes of Canada (SLC) database
  The SLC series of maps summarize soil and landform data at a scale of 1:1,000,000 for the entire country.
- Provincial soil survey maps
  Over the last 50 years, all provinces have undertaken a soil survey program and have mapped 90% of the agricultural areas in Canada. The scale of the mapping and the attributes associated with each of the map units varies greatly among the provinces.
- Data from provincial soil testing laboratories
  Provincial and private agricultural soil testing labs across the country annually measure soil carbon on thousands of samples, and have, in many cases, built an large archive of soil analytical data over the last decade.

Scaling-up

Determining changes in SOC stocks on a regional or national level will require scaling-up site-specific model predictions of soil carbon. The appropriate techniques for scaling-up site-specific estimates depend on the scale at which the regional estimates are applied. Scaling-up options include:

- Scaling Estimates Derived from SLC Polygons
  In the case where provincial soil survey map units or Soil Landscape of Canada polygons are the basic units to which model runs are applied, then an average value for each model input parameter (SOC, texture, etc.) is used to arrive at a change in mass of soil carbon for that polygon. Regional and national estimates of changes in soil carbon are obtained by summing the values for all the polygons in the region or nation.

- Scaling Estimates Derived from Landscape Elements
  In a non-level landscape, many of the key driving variables will vary significantly within the soil map unit or SLC polygon according to topography. Therefore, it is appropriate that topography-based landscape positions be used as the spatial unit for the modeling and scaling-up process. In this option, a soil polygon is divided in landscape units. In the case of the SLC polygons in Western Canada, the distribution of landscape types can be derived from existing provincial soil survey mapping.

Options for Verification

In the context of a framework for measuring and monitoring changes in soil carbon, verification means ensuring that the output of the framework (i.e. national estimates of carbon sequestration) are accurate within the confidence criteria that have been established. Two options have been identified for the verification of the proposed measuring and monitoring framework for soil carbon stocks:

- A 'Performance-based' Verification

  A performance-based verification would involve demonstrating that model outputs of changes in SOC sequestration are consistent with field observations, at a given level of statistical certainty. This would involve an extensive sampling program, where estimates of change in soil carbon are confirmed through direct measurement, using a sufficiently large and statistically valid sample.

- A 'System-based' Verification

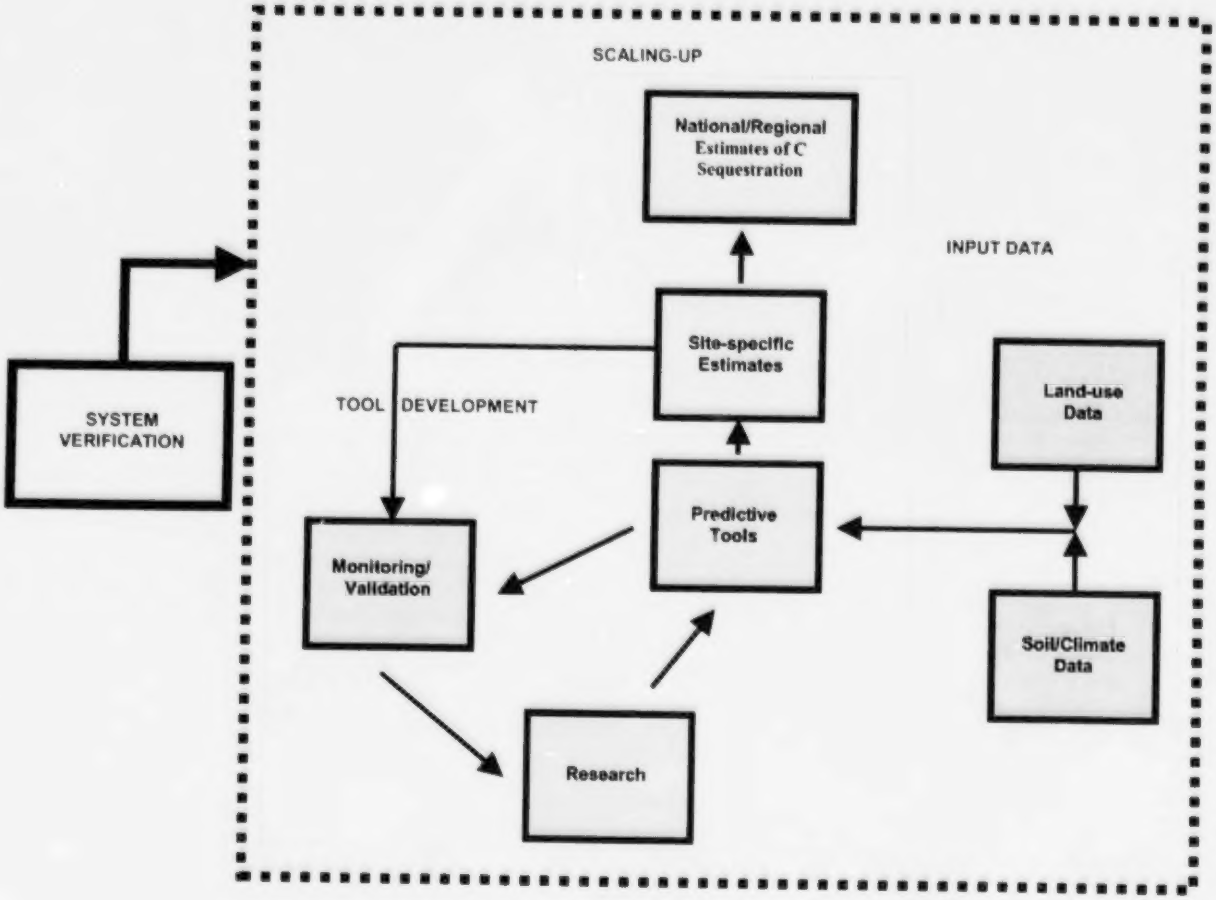
  A key concept to understanding a systems-based approach is that the outputs (national estimate of changes in soil carbon) from the system are valid if it can be demonstrated that each of the scaled-up component elements of the system (i.e. predictive tool, soil, climate and land-use database) are valid and can be verified. In other words, the validity of the whole is equal to the validity of the sum of its parts. The systems-based approach to the verification of the framework shifts the focus of a verification program from the accuracy of the national estimates of carbon sequestration to the accuracy and completeness of the component parts of the measuring and monitoring framework. Some members of the Table, however, noted that there may always be stakeholders, scientists or other countries' governments who will still not be convinced of the validity of the system-based verification unless they see the accompanying hard measurement data to validate claimed estimates.

5.3.2.2 Recommended Options

The preferred options were selected on the basis of the following criteria:

- likelihood of contributing to an accurate and verifiable framework;
- gaps in data for each option and deficiencies in research;
- likelihood of being able to meet data and research needs prior to the start of the commitment period; and
- applicability to the entire agricultural zone in Canada.

Figure 5.2: Soil Carbon Stocks Monitoring and Measurement Framework



Preferred Option: Predictive Tool

A combination model consisting of the CENTURY model and a rule-based system would be the most manageable and verifiable predictive tool. Although there are several process models available, the overriding advantage of the CENTURY model is its international acceptability, the large body of research that has already gone into its development, and its success in modeling prairie and grassland agroecosystems. The recommendation of CENTURY and a rule-based system is based on the information available at the time this report was written. Further process-based models may be developed which are superior to CENTURY; therefore, ongoing model evaluation and development is an explicit part of the proposed framework (see also section 5.3.4).

Preferred Option: Land-Use and Management Data

The framework requirements for land-use and land-use management can best be met through a combination of census data and remote sensing, backed up and verified through a field scouting program. An important provision of this recommendation is that the data collected during the agricultural census must be refined to meet the needs of the framework, including the need to adjust census dates such that they correspond to the beginning and end of the commitment periods. If this is not possible, then there will have to be increased reliance on remote sensing and field scouting.

Preferred Option: Soil/Climate Data

The most appropriate soil database must balance the need for accuracy and verifiability of the data against the need for having a manageable number of discrete soil units, such that the modeling and scaling-up exercises are not too costly and time consuming. In this respect, the Soil Landscapes of Canada database is the recommended source of soil data, recognizing that considerable work is still required to fill data gaps and to improve the existing data. It is believed that data from the provincial soil testing laboratories could be useful in filling some of the data gaps, although the adequacy of these data, and their accessibility needs to be further investigated.

Preferred Option: Scaling-up

Although scaling-up from landscape elements would result in more representative estimates of changes in SOC for each SLC polygon, the accuracy of the method is dependent upon the quality of the provincial soil database. Only a small proportion of provincial soil survey map information from across Canada is of sufficient quality and detail to allow landscape elements to be used as the basis of scaling-up for SLC polygons. For this reason, using a weighted average of soil parameters within a SLC polygon as input to the predictive tool is recommended. While the SLC database represents the best soil database option, techniques for linking the SLC data to census data require further development. Changes in soil carbon estimated from the predictive tools for each polygon are summed for all polygon nationwide.

Preferred Option: Verification

A 'systems-based' approach is the preferred verification system since it will be impossible or impractical to verify changes in soil carbon using a direct measurement approach (i.e. through verification of the performance of the framework) given the inherent spatial variability in soil carbon and the short duration of the five-year commitment period. Therefore the systems-based approach to the verification of the framework shifts the focus of a verification program from the accuracy of the national estimates of carbon sequestration to the accuracy and completeness of the component parts of the measuring and monitoring framework.

The systems-based verification would involve an "internal" and an "external" verification component. The internal verification includes the iterative inspection and verification of each framework component (predictive tools, soil/climate data, land-use data, etc.) in both its development and implementation. The external verification focuses on the evaluation of the system as a whole. The external verification would involve an evaluation by an outside party of how well the framework is performing in meeting its stated objectives; namely to provide accurate and reliable measurements of soil carbon sequestration during the commitment period.

It is proposed that a Management Systems approach be adopted for the external verification, whereby an external audit of the Management System is conducted. A Management Systems approach is a well-defined methodology for planning, implementing and checking the performance of any system. It has been applied to many environmental management problems, and is the basis of ISO 9000 and ISO 14000 quality management systems. The external verification of Canada's National Estimates of Carbon Sequestration will involve an audit by an external auditor of the Management System. The audit will involve the systematic collection of objective evidence of the implementation of the plans and procedures for measuring and monitoring changes in SOC. Verification of the National Estimates will depend on the degree to which it can be demonstrated in the audit that all the system components have been developed and verified within a system of rigorous checking and improvement.

5.3.3 Preliminary Costs Estimates

The evaluation of the various framework options included the identification of shortcomings, barriers and pre-conditions for implementation, including data gaps, research needs and financial costs. The greatest estimated cost in the development and implementation of the measuring and monitoring framework will be associated with the development of a rule-based system and refinement of the CENTURY model (estimated $8.42 million). This task will require intensive research to help close data gaps associated with methodology for: estimating maximum carbon storage potential; calibrating a rule-based system; quantifying uncertainty in model prediction; and improving understanding of carbon inputs to the agro ecosystems and adjacent ecosystems where the CENTURY model may perform poorly.

Development of land-use and management data, modifications to the census survey, such as including better coverage in Eastern Canada and better data on tillage practices and rotations, will be required for the inclusion of census data in the framework. Further research will be required to: improve linkages between census data and the SLC database; refine the ability of the LandSat to identify changes in tillage practices; and to determine the level of sampling required for a field verification of land-use management changes. Total development costs associated with the development of the required Land-Use and Management Data are estimated to be approximately $0.34 million.

The most significant challenge with respect to developing soil and climate data will be improving soil data and addressing gaps in the SLC soil attribute database. Total development cost associated with addressing deficiencies in soil and climate data are estimated to be approximately $0.65 million. Scaling-up site-specific estimates within a 20% level of confidence will require further research to determine the propagation of error. This research is expected to span two years and cost approximately $0.08 million.

Implementation of the framework will involve modeling changes in soil carbon, collecting LandSat data, implementing a field scouting program and collecting census data during the commitment period. Implementation cost for the initial commitment period is estimated to be $4.37 million, while implementation costs for subsequent commitment periods are estimated to be approximately $3.8 million because data derived from the end of the previous commitment period will be used to initiate the following commitment period. Therefore, a preliminary gross estimate cost for the development and implementation of the entire framework is $12 million to be spent between 2000 and the end of the first commitment period in 2012. It should be reinforced that this estimate is very preliminary and it is a little artificial at this point to provide a cost estimate, given the lack of information.

5.3.4 Research Priorities

The main long-term objective of the research into agricultural soil carbon processes for the purposes of implementing the Kyoto Protocol is to improve predictive models (such as CENTURY) that can be used to predict, in an internationally acceptable and verifiable way, the comparatively small changes in soil carbon storage (in relation to the total store in the soil) in agroecosystems that are likely to result from changes in soil management and from global change. There are a number of important initiatives required to address this challenging task. High priority programs that can achieve significant results within the next two to five years include the following:

- devising methods that estimate the maximum carbon storage potential for each soil/climate/ management combination, and determining the present status of soils relative to that sink potential;
- improving our understanding of the role of, and tools to measure, the effect of erosion on SOC storage within

agricultural land, and the effect of eroded soil plus nutrients on adjacent ecosystems (wetlands and riparian zones) within dominantly agricultural landscapes;

- determining, for selected C-conserving systems (e.g. no till) the overall net effect on radiative forcing in the atmosphere (full-cycle accounting) with attention to energy use, the energy cost of inputs such as fertilizers and net impacts on emission of other greenhouse gases, notably nitrous oxides;
- measuring CO_2 fluxes from selected representative agroecosystems, as verification of regional estimates derived from models; and
- improving our estimates and understanding of carbon inputs in different agroecosystems, especially: below-ground inputs as roots and root exudates; and retention of carbon already stored in manures and biosolids when they are applied to land.

In addition, there are several priority programs that will require a longer term investment of a decade or so to achieve the desired results. These include:

- establishing a series of long-term tracer studies that are representative of the major soil/climate regions, to evaluate carbon dynamics under the dominant, often recently developed or developing, agronomic systems — particularly those considered to have carbon sequestration potential. These studies, established and maintained across Canada, would be invaluable in refining and verifying computer models that predict SOC change; and
- further developing and refining simulation models for soil carbon, especially to: improve the sensitivity of the models to predict short-term changes in stocks in response to management; use measurable carbon fractions rather than conceptual pools; improve consistency and accuracy of model initialization; and test the reliability of the models for estimating both changes in SOC as well as CO_2 fluxes. In addition to the comprehensive models used in research, there is a need to develop simplified versions of such models that are understandable to the layperson, that rely on readily available input variables, and that are potentially applicable to other nations.

5.3.5 Recommendations and Next Steps

The development of the proposed measuring and monitoring framework outlined in section 5.3.2.2 would most likely involve researchers across Canada, including those from the federal and provincial governments, and various universities with relevant research programs. In consideration of the impending timeframe for framework development and implementation prior to the commitment period, it is crucial that the roles and responsibilities be designated as soon as possible. The necessary procedures for each measuring and monitoring system element should be established. A documented protocol for external examiners to assess the effectiveness and level of implementation as specified in the system-based verification plan should be provided.

Recommendation 5.2: a steering committee composed of governments' representatives and stakeholders should be established and provided with adequate commitment and funding, to coordinate the development and implementation of the agricultural soils carbon stocks measurement, monitoring and verification framework.

The development and implementation of the proposed monitoring and measuring framework requires the completion of four major tasks prior to the commitment period. The first step is the development of the Predictive Tool. The second step, concurrent with the first, is the development of the soils and climate database. The third step is the development and verification of the methodology for measuring land-use and land management prior to the commitment period such that the actual land-use data can be collected at the beginning of the commitment period. Finally, the refinement and verification of the technique for scaling-up site-specific estimates would be done, but cannot start until the predictive tools, soils database and land-use databases are well developed. Given that there is much uncertainty associated with the technique for scaling, development and evaluation of all scaling options should start early in the implementation schedule.

6. WETLANDS CONSERVATION

6.1 Introduction

The Sinks Table Foundation Paper (National Sinks Table, 1998) introduced the subject of wetlands as possible carbon sinks under the Kyoto Protocol. Neither agricultural soils nor wetland carbon sinks are currently acknowledged in the Protocol, but Canada's position is that forest carbon stocks include both the above- and below- ground biomass and soil carbon, and that agricultural soil carbon should be included. Wetlands cover approximately 14% of Canada's land surface and contain over 150 Gt C; approximately 60% of Canada's carbon stock. Since wetlands are such prominent components of both forest and agricultural landscapes, one could expect that soil carbon in the Kyoto Protocol would also include wetlands, should agricultural soil management be confirmed as an accountable sink category and/or should C stocks encompass the soils pool.

Following the release of the Foundation Paper in November 1998, wetland carbon sinks have been the focus of further workshops and studies including:

- Climate Change Action Fund (CCAF) workshop on Carbon Flux Processes in Terrestrial Ecosystems, Downsview, 18-19 January 1999.
- Feasibility study on Wetlands and Climate Change (Patterson, 1999).
- Workshop on Carbon Sequestration in Prairie Wetlands, Oak Hammock, 19-20 April 1999.

In many ways, wetlands are a sustainable development and climate change paradox. In contrast to the globally significant industries of forestry and agriculture, wetlands do not produce commodities that are currently a factor in the market economy. Thus, from an economic and public policy perspective, wetlands have tended to be the forgotten landscape. Historically, wetlands have been considered to be wastelands, so that wetland conservation efforts have had to work against the grain of economic development. This is in marked contrast to the functional ecosystem benefits provided by wetlands (e.g. flood prevention, groundwater recharge, nutrient assimilation, degradation and storage of toxic chemicals and wildlife habitat, among others), which are at the top of any scale of externalized economic or ecological valuation (Costanza *et al.*, 1997).

The definition of wetlands and their distribution and abundance in Canada are described in the Sinks Table Foundation Paper. As steward of over 24% of the world's wetlands, Canada has a unique responsibility for their conservation and sustainable use. Most of Canada's northern peatlands are not impacted by man. Wetlands in the southern working landscapes have experienced the largest human impact, and as a result are the focus of this paper, as being part of the scope of the Framework Convention.

While a formally recognized definition of wetlands is an important starting point, any consideration of carbon sinks and sources is a function of land-use practices and wetland conservation programs — or in the terms of the Protocol, human-induced land-use and land-use change. Wetland conservation, as exemplified by the North American Waterfowl Management Plan (NAWMP) habitat Joint Ventures (JVs) is a landscape-scale enterprise, encompassing wetland basins, margins or riparian zones and associated uplands (Patterson, 1994). Through voluntary, non-regulatory partnerships with landowners and managers, the NAWMP JVs are globally acknowledged as leading demonstrations of the sustainable development of landscape resources (Tyrchniewicz and Wilson, 1994). As a value-added component of sustainable agriculture and forestry, wetland conservation provides win-win land-use options for land managers.

Wetlands have the highest carbon density of all terrestrial ecosystems. They are among the most productive ecosystems in the world, and have properties that reduce the rate of organic matter turnover. Hence, wetland ecosystems are characterized by the two primary factors controlling carbon sequestration, high rates of organic matter input and reduced rates of decomposition. There is considerable opportunity for managing that capability to enhance carbon sequestration while sustaining other valued ecosystem functions (USDOE, 1999). Recognition of wetlands in the Kyoto Protocol would bolster their conservation and sustainable use, and would embrace a more comprehensive vision of sinks in the agreement, while as will be seen further, meaningful source and sink information is lacking.

In response to international trade wars in the 1980s and early 1990s, substantial commodity subsidies were provided to grain and oilseed producers as a means of staying competitive in world export markets. It is widely believed that an unintended and perverse effect of these subsidies was to support the conversion of marginal lands and wetlands to agricultural production, particularly in the Prairie/parklands (Patterson, 1993). Parklands are the transition zone between the Prairies and boreal forest. Agricultural subsidies were effectively eliminated in the 1995 Federal Budget, and so have the market and land-use distortions they caused. The marginal lands and wetlands that were converted during the subsidy years are of critical importance to carbon sequestration management in agricultural soils. Fortunately, in a post-subsidy world, the combined efforts of sustainable agriculture, conservation cover, wetland conservation and carbon sequestration programs have a high probability of regaining these losses.

The purpose of this chapter is to address what makes a wetland a sink or a source, how this is impacted by human-induced land-use and land-use changes in the agricultural and forested working landscapes, and finally, outlining the potential for emissions reduction and sink enhancement. The science subsections of this chapter will focus on the natural cycle of greenhouse gases through wetlands, what impacts this natural cycle and the potential measurement and verification techniques. The management "options" from this paper will be based on wetlands in those landscapes that are impacted by forestry and agriculture, the largest proportion of which are located in the Prairie/parkland region.

6.2 Natural Wetlands and Riparian Areas: Sources and Sinks

6.2.1 The Carbon Cycle in Wetland Ecosystems

The global carbon cycle consists of storage pools and flows or fluxes, with any imbalance between influx and efflux changing the size of the pools. There is good evidence that humans have altered the global carbon cycle during the past 200 years, particularly through fossil fuel consumption and land-use change (Schlesinger, 1997). This has resulted in an on-going increase in the atmospheric carbon pool, at present estimated to be increasing by about 3.4 Gt C yr^{-1} (Table 6.1).

Table 6.1. The Present-Day Global Carbon Cycle

Carbon Pools (Storage)	Gt Carbon
Atmosphere	750
Oceans	38,000
Soils (Wetland Portion)	1600 (455)
Land Plants (Wetland Portion)	560 (8)
Carbon Fluxes (- Inputs) (+Outputs)	**Gt C yr^{-1}**
Fossil Fuels	+5.4
Deforestation and Land Use	+0.9 to +1.6
Plant Respiration	+60
Microbial Respiration	+60
River DOC and DIC Transport	+/-0.8
Photosynthesis	-120
Peatland Accumulation	-0.07
Ocean Sediment Burial	-0.1
Oceanic Carbonate Equilibrium Processes	-2
Accumulation in Atmosphere	-3.4
Missing Sink	-1.4 to -1.6

(Note: 1 Gt = 10^{15} g = 1 Pg)
Modified from Houghton, 1990 and Schlesinger, 1997.
DOC – dissolved organic carbon. DIC – dissolved inorganic carbon

Inputs of carbon to wetland ecosystems occur via uptake of carbon dioxide (CO_2) through photosynthesis by vascular plants, non-vascular bryophytes and algae. In Prairie and boreal wetlands, significant carbon inputs may also be derived from surrounding ecosystems in the form of agricultural soil erosion and deposition, sediment and dissolved organic carbon (DOC) loading from rivers, and organic detritus such as leaf litter. Outputs of carbon from wetland ecosystems include plant and microbial respiration of CO_2, microbial production of methane (CH_4) and DOC lost via leaching and export to adjacent water bodies.

6.2.2 Carbon Sequestration

The global soil carbon pool of 1600 Pg is more than twice as large as the atmospheric carbon pool of 760 Pg (Raich and Potter, 1995). Wetlands in the Northern Hemisphere store an estimated 455 Pg of carbon, which is about 30% of the global soil pool.

Carbon storage occurs in both short-term and long-term reservoirs. Plant and algal biomass and DOC in the water column represent short-term (seasonal) sequestration of carbon in wetlands. Sequestration in sediments of DOC and undecomposed organic matter from autochthonous production and allochthonous inputs represents long-term (years to decades) carbon storage in wetlands. Carbon storage occurs when primary production is high and exceeds the rate of decomposition, or conversely, when the rate of decomposition is slowed by anoxia and cold temperatures, resulting in an accumulation of undecomposed organic matter. Wetlands tend to be highly productive ecosystems (up to 1300 g C m^{-2} yr^{-1}), comparable to tropical forests (800 g C m^{-2} yr^{-1}), in terms of annual net primary productivity among global ecosystems (Schlesinger, 1997). Coupled with anaerobic soil conditions that slow the rate of decomposition, these ecosystems have excellent potential for long-term carbon storage. While the vast area of peatlands accounts for the majority of carbon storage in wetlands in the Northern Hemisphere, the potential for affecting change in carbon storage on a time-scale of years to decades may lie with restoring Prairie wetlands.

In northern peatlands, annual net primary productivity is low (130 g C m^{-2} yr^{-1}), but retardation of decomposition because of anaerobic conditions and cold temperatures tends to result in increased sequestration of carbon. The current rate of carbon accumulation in northern peatlands is 0.076 Pg yr^{-1} (Gorham 1991, Clymo *et al.*, 1998). The capacity for increased carbon storage in peat is small, given that accretion of peat in northern peatlands is a slow process, dependent on low primary productivity and reduced rates of decomposition. In terms of functioning as a net source or sink, undisturbed northern peatlands may just hold the balance between carbon sequestration and methane emission (Schimel *et al.*, 1995).

Prairie/parkland wetlands presently store significantly more carbon than the surrounding agricultural land. Therefore, reclaiming marginal agricultural lands and restoring them to wetlands or riparian areas has the potential for increasing carbon sequestration. This was the expert consensus of wetland scientists at the recent Carbon Sequestration Workshop (April 19-20, 1999, Oak Hammock Marsh). An on-going study of 204 wetlands in North Dakota, South Dakota, Minnesota and Iowa indicates that pristine (non-farmed) wetlands store twice as much carbon as wetlands that have been drained and converted for agricultural use (Euliss *et al.*, 1999). This suggests that 50% of the original soil organic carbon was lost when these wetlands were first drained for agriculture. Preliminary research indicates that when these wetlands are restored, projected recovery to pristine wetland organic carbon levels would take 10 years for the shallow marsh zone and approximately 20 years for the wet meadow zone (Euliss *et al.*, 1999).).

6.2.3 Greenhouse Gas Emissions

In terms of greenhouse gases, wetlands can either be sources or sinks of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Because of their complex biogeochemistry, they may function as sinks for one gas while acting as sources for others. Wetlands may also change from sinks to sources due to anthropogenic impacts such as increased nutrient loading, draining, in-filling, flooding, burning and vegetation change.

On a global scale, wetlands are minor sources of carbon dioxide and nitrous oxide emissions, and major sources of methane (Table 6.2).

Table 6.2. Wetland Contribution to Global Annual Greenhouse Gas Emissions.

Greenhouse Gas	Wetland Emissions	Total Global Emissions	% Contribution
Carbon Dioxide	8.5 Tg yr^{-1} (1)	7000 Tg yr^{-1} (2)	0.12
Nitrous Oxide	0.133 Tg yr^{-1} (3)	7.1 to 12.7 Tg yr^{-1} (4)	0.8 to 1.4
Methane	113 Tg yr^{-1} (5)	540 Tg yr^{-1} (5)	21

(1) Gorham, 1991.
(2) Houghton, 1990.
(3) Freeman *et al.*, 1993.
(4) Davidson, 1991.
Bartlett and Harriss, 1993.
(Note: 1 Tg = 10^{12} g)

Marsh and floodplain wetlands in the North American agricultural landscape contribute significantly less atmospheric methane (<2 Tg yr^{-1}) than northern peatlands (14-18 Tg yr^{-1}) (Bartlett and Harriss, 1993). The lower methane emissions measured in marshes versus peatlands can likely be attributed to higher rates of methane oxidation in marsh ecosystems. Emergent vegetation and thick mats of benthic algae in these wetlands provide oxygen microzones where methane oxidation can occur. When algal mats are present, up to 90% of the potential methane flux can be consumed by methane oxidation (King, 1990; Wang *et al.*, 1995). Many studies have noted a trade-off between methane and carbon dioxide emissions related to water levels and anaerobic conditions in wetlands (Roulet *et al.*, 1993; Alm *et al.*, 1999). It had been estimated that the magnitude of the increase in CO_2 emissions with drawdown of wetlands and peatlands would far outweigh any potential benefit of decreased CH_4 emissions.

Carbon dioxide fluxes are approximately balanced between gross photosynthetic production (input) and plant and microbial respiration (output), with storage in soils and peat corresponding to any excess primary production (Houghton, 1990). Anaerobic wetland soils generally have lower rates of carbon dioxide emission than terrestrial soils (4 vs. 7-8 g C m^{-2} d^{-1}) (Raich and Potter, 1995).

Emissions of nitrous oxide from Northern Hemisphere wetlands are low (Groffman and Taylor, 1996). Natural waterlogged soils have been shown to act as sinks or negligible sources of N_2O with emissions of <0.04 kg N ha^{-1} y^{-1} (Martikainen *et al.*, 1993). Nitrous oxide production is particularly favoured by fluctuating soil water content, high organic carbon availability and high inorganic nitrogen availability (Freeman *et al.*, 1997). While Prairie wetlands may provide high organic carbon availability they generally have continuously waterlogged soils and often tend to be nitrogen-limited systems. Under saturated conditions (>80% water-filled pore space) nitrous oxide is consumed and nitrogen gas becomes the major end product of denitrification.

While prairie wetlands do emit methane and nitrous oxide by nature of their biogeochemical functioning, these emissions may be offset by their capacity to store carbon, allowing these wetlands to function as net global carbon sinks. However, scientists agree that we are not at the point where it is possible to estimate the sink and source strengths of Canadian wetlands in a meaningful manner (Hengeveld and Beaulieu, 1999).

6.3 Human-Induced Impacts on Wetlands, Riparian Areas and Associated Uplands – Implications for Sources and Sinks

6.3.1 Activities in the Forest and Agricultural Landscapes that Directly or Indirectly Impact Wetland Source or Sink Capability

Peatlands have been drained for the growth of crops and trees, the production of fuel and the harvesting of horticultural moss (Armentano and Menges, 1986). Carbon dioxide emissions tend to increase due to drainage and degradation of northern peatlands (Roulet *et al.*, 1993; Funk *et al.*, 1994; Alm *et al.*, 1999). Long-term drainage of peatlands is estimated to be producing CO_2 at the rate of about 0.0085 Pg yr^{-1}, while burning of fuel peat adds an additional 0.026

Pg yr^{-1} (Gorham, 1991). In Sweden, farmed organic soils represent less than 10% of total arable land, but contribute as much as 10% of the total national anthropogenic CO_2 emission (Kasimir-Klemedtsson *et al.*, 1997). Draining of peatlands also significantly increases nitrous oxide emissions (Freeman *et al.*, 1993; Regina *et al.*, 1998). In Finland, N_2O emissions from farmed organic soils amount to 25% of total anthropogenic N_2O emissions (Kasimir-Klemedtsson *et al.*, 1997).

In Western Canada, where 80% of arable agricultural land is located, it has been estimated that cultivation has resulted in the loss of 20 to 30% of soil organic carbon (SOC) originally stored in these soils prior to cultivation (Janzen *et al.*, 1998). Prairie/parkland wetlands may lose up to 50% SOC when converted to agricultural usage (Schlesinger, 1997; Euliss *et al.*, 1999). It has been estimated that at least 75% of Prairie/parkland wetlands have been lost through agricultural drainage, many of which are subsequently only marginally productive under crop management (Environment Canada, 1986). Also, as noted in section 4.1.6.1, it has been estimated that up to 1 million ha of degraded riparian areas are present in the three Prairie provinces that could be restored.

Mitigation is two ways: restoration of the actual wetlands basins through re-establishment of aquatic and riparian vegetation, as well as soil C restoration in the riparian zones and uplands that may be cultivated. The degradation of riparian zones and associated uplands via cultivation or overgrazing has the direct impact of reducing the amount of vegetated habitat available to sequester carbon, but also has a negative impact on the remaining wetland through nutrient loading associated with runoff of fertilizer, pesticides and soil erosion. Suggested cropping practices that may restore some portion of lost SOC to agricultural soils include reduction in tillage, utilization of perennial forage cover and organic amendment of the soil.

Restoration of marginal agricultural land to wetlands appears to offer the potential of doubling carbon sequestration in these areas. Restoration and enhancement of these systems has important implications for the development of wildlife habitat and other wetland functions such as carbon storage.

6.3.2 Measures to Reduce Sources and Enhance Sinks Capabilities of Wetland Basins, Riparian Zones and Associated Uplands

6.3.2.1 Policy Requirements

Federal and Provincial government policy and economic instruments will be required to encourage landowners and managers to restore and enhance the carbon sink capability of drained or degraded wetlands and riparian zones. These would be in the form of tax instruments such as tax credits and accelerated depreciation for the purchase of conservation equipment. Incentives and direct funding for wetland restoration and protection, as developed and refined by the NAWMP JVs, need to be expanded in both magnitude and partnership base. A system to allow for the sale of carbon credits would provide value-added incentives to further encourage wetland conservation initiatives.

6.3.2.2 Program Requirements

As seen above, the most significant agricultural threats to wetland and riparian ecosystems include: drainage and land clearing, annual cultivation or disturbance, exotic plant invasion, sedimentation, increased nutrient loading and contamination from soil erosion. Other threats include: urban and industrial expansion, hydro development, port and harbour development and drainage for forestry activities.

Incentive programs need to be designed to encourage the adoption of land management practices that will restore and enhance wetlands and increase their capability to sequester carbon. Practices that will increase the quantity and improve the quality of wetland and riparian areas include: reforestation, reduced tillage, elimination of summerfallow or conversion to direct seeding, residue management, adding nutrients to deficient soils, use of cover crops and winter crops, growing more perennial forages in crop rotations, contour cultivation and strip cropping, planting riparian areas, saline and eroded lands to perennial grasses, shrubs and trees, improved grazing management and restructuring degraded landscapes such as grassed waterways.

Many of these conservation and "best management" land-use practices are part of existing or proposed strategies to encourage sustainable land use in both the forest and agriculture landscapes, as described in Chapters 3 and 4. However, many barriers exist which reduce the adoption rate of these practices on the majority of the agricultural and forestry landscapes. The development of long-term programs which provide incentives for adoption, reduces risk and removes policy barriers to the adoption of these conservation and "best management practices" will benefit wetlands and enhance their ability to sequester carbon.

6.3.3 A Canadian Conservation Cover Program

One of the most effective ways of protecting and enhancing wetlands, waterways and riparian areas is to re-establish perennial grasses, forbes, shrubs and trees and to allow the land to revert to natural vegetation over a long period of time. This practice is feasible on most marginal lands, but may also be applicable to small areas of productive agriculture and forest lands. Land planted to permanent perennial grasses or trees would control wind and water erosion, sequester carbon, improve water quality by reducing pesticide, fertilizer and soil movement into streams and wetlands adjacent to annual cropland and provide wildlife habitat.

In the Prairie/parklands many of these marginal agricultural acres are salinized and occur as "bath tub rings" adjacent to wetlands and riparian areas. In spite of the fact these acres are cultivated and seeded every year, they produce little in the way of annual crop production and the best land use would be to convert them to perennial grass or legume cover. In Saskatchewan alone, approximately 355,731 hectares of land are estimated to fall in this category. Besides being useful as wildlife habitat, these areas will also function as carbon sinks.

A consortium of NAWMP partners has developed a concept proposal for a Canadian Conservation Cover Program (CCP). The objective of the CCP is the sustainable use of agricultural lands, achieved through conversion of cultivated lands to grasses, forbes, shrubs and trees. The program would pay Canadian landowners to establish permanent vegetative cover on the agricultural landscape. It would extend and expand upon the highly successful Permanent Cover Program established by the federal government in 1989. The program would be integrated with the many small-scale grass and forage conversion programs presently being implemented by conservation and agricultural agencies across Canada, as indicated in Chapter 4. Program design would insure that the conservation and enhancement of wetland basins is an integral part of the initiative.

6.3.4 Impacts of Climate Change on Wetlands

Many wetlands, particularly in the north, are not directly affected by direct human-induced impacts. However, even the most remote wetland regions may be subject to the effects of a changing climate. A combination of increased temperature and constant or reduced precipitation in some areas may result in decreased runoff and lowered ground water levels, causing the drying of some wetlands and a decrease in size or change in wetland types of some others. Increased carbon dioxide concentrations in the atmosphere may change the physiology of some wetland vegetation. Wetland types likely to be substantially impacted by climate change include:

- *Coastal and estuarine wetlands*. Coastal and estuarine wetlands may be destroyed if sea level rise exceeds the rate of deposition and if inland migration is not possible. Salt marshes may change in species composition or vegetation types. Submerged aquatic vegetation, coastal marshes, coastal bottomland hardwood forests and other wetland types may all be affected.
- *Tundra (permafrost) wetlands*. Significant areas of permafrost wetland may be converted to open water by temperature increases that melt the permafrost underlying these wetlands, causing the release of carbon dioxide and methane.
- *Peatlands*. In addition to permafrost wetlands, significant areas of other types of peatlands may be affected by a combination of temperature increase and the lowering of groundwater tables, thereby exposing peat to oxidation. Increased temperatures could increase wetness in some instances and decrease it in others.
- *Prairie/parkland potholes*. Reductions in wetland size and the disappearance of many wetlands can be expected with increased temperature and changing precipitation patterns in the Prairie/parkland Pothole Region.
- *Swamps and river/lake fringe wetlands*. In areas where temperature is expected to increase and precipitation decrease or remain steady, some depressional wetlands will dry, decrease in size or convert to uplands.

All of the above have implications with respect to the potential inclusion of soils and/or wetlands in the Protocol. Their inclusion would mean countries would have to face all the consequences, including the climate change impacts on carbon fluxes, should these not be distinguishable from "direct anthropogenic" impacts. Consequences need to be adequately assessed when developing a negotiating strategy.

6.4 Measurement, Verification and Modeling Wetland Carbon Sinks

6.4.1 Information Needs for Understanding Carbon Budgets

Developing carbon budgets for any ecosystem requires information on inputs, outputs and changes in storage within the system. Inputs of carbon to wetlands include photosynthetic uptake by plants and algae, dissolved inputs in surface/groundwater and precipitation, as well as particulate input through water and air. Outputs are through respiration by living organisms and during decomposition processes, loss of dissolved forms through surface/ground water outflows, and particulate loss primarily in surface water outflows. Within the wetland, carbon is found in both short-term stores (including living organisms, decomposing organic matter, and dissolved and particulate material in the water column) and longer-term stores (e.g. organic sediments). Information is needed on all these components to develop complete carbon budgets for wetland systems.

The recent workshop on carbon sequestration in Prairie/parkland wetlands at Oak Hammock, Manitoba, reviewed the current knowledge base related to the various components of the carbon cycle in Prairie wetlands and found there was a broad range of information available from a variety of sources. A modeling exercise was recommended to organize this available information and identify specific research needs. During this discussion, three critical information gaps were identified that require immediate attention. These are wetland gas exchange rates (including carbon dioxide, methane and nitrous oxide), wetland/riparian/upland interactions regarding carbon flows and stores, and carbon accumulation rates in the soil/litter column of wetlands. It was also noted that all information must be extrapolated to the landscape level to allow regional and national assessment of carbon stores and changes in those stores.

6.4.2 Status of Technology for Measuring/Verifying Carbon Storage and Fluxes in Wetlands

A variety of techniques are available to monitor and verify carbon fluxes and stores in wetlands. Determination of carbon inputs and outputs in association with water flows can be determined by volume determinations of the flows involved (surface/ground water, precipitation) and the concentration of carbon (dissolved/particulate, organic/inorganic) in those flows. Atmospheric uptake of carbon can be determined by biomass accumulation (above- and below-ground) of the primary producers in the system. Carbon inputs and outputs can be integrated by using stable isotopes to determine carbon pathways and allochthonous (exterior) versus autochthonous (within the wetland) carbon inputs. Decomposition studies can follow the movement of carbon from the death of the plant/ algae through to burial of material in the sediments. While requiring complicated techniques and analyses, gas exchange studies can monitor gas losses (carbon dioxide, methane and nitrous oxide) from the system through respiration and decomposition processes. Sampling of the soil profile can provide information on carbon stored in wetland sediments.

While there are techniques available for detailed carbon studies, future efforts must address the need for simple and rapid assessment of the carbon stores in wetlands and the changes in those stores over time. This is an important challenge for the wetland scientific community.

6.4.3 Extrapolating from Individual Sites to Regional/National Carbon Values

The information on carbon fluxes and stores for individual wetlands and wetland types must be extrapolated to larger regional and national values. Wetlands must be considered within the context of the overall landscape (i.e. the wetland, adjacent riparian zone and associated uplands). Modeling efforts must take into account the interaction of these landscape components as carbon store values are extrapolated to regional estimates. This will require refinement of the existing modeling techniques and development of detailed wetland inventories to allow extrapolation based on areal extent and changes in wetland types.

6.4.4 Wetlands Inventories

Remote sensing has become an important tool in the inventory of natural resources including wetlands. A wide variety of sensing devices are available, from airborne to earth observation satellites. The main remote sensing data sets in use are based on data from LANDSAT-Thematic Mapper (TM) satellite imagery. For example, Ducks Unlimited Canada has generated a wetland habitat inventory of the Prairie and parkland regions for the period 1985 to 1996 from the LANDSAT-TM imagery.

A debate in ongoing as to whether the present methods for classifying wetlands at a regional level can also be used for monitoring changes over time. Ducks Unlimited has indicated that 80% of the wetlands on the Prairie and Aspen parkland region are less than one hectare in size, and many are only seasonally or temporarily inundated with water. Due to this small size, some experts feel that the spatial resolution of LANDSAT may be insufficient. However, new high-resolution satellite imagery is now available and has exciting implications for wetland remote sensing. A cooperative project of national agencies with remote sensing expertise should explore the feasibility of these advances for providing a reliable and repeatable inventory of wetlands in Canada.

6.4.5 Modeling Carbon Cycling/Storage in Wetlands

Effective modeling will reduce the uncertainty of estimates of carbon cycles in wetlands. Various model types are available for modeling carbon sequestration. The CENTURY Model (addressed in section 5.3), a widely accepted model focusing on agricultural soil carbon dynamics, has not been applied to wetlands. It simulates soil organic carbon in a range of cropping systems, rotations and tillage practices in the Great Plains, and has been used to simulate grasslands, forest and savannas. The model would need considerable modifications to be applied to wetlands.

A conceptual model has been developed specifically for carbon stocks and fluxes in Prairie wetlands in a collaborative effort involving scientists at the National Water Research Institute, Saskatoon, Saskatchewan and the University of Saskatchewan. In this model, the carbon dynamics of the low Prairie, wet meadow, shallow marsh, deep marsh and open water zones of wetlands are simulated. The model structure has been developed to account for spatial variability and the difference in scale on processes such as biological productivity. The model incorporates linkages to surrounding land use which influences wetland functions to ensure that the model simulates wetland function within the context of the overall landscape. In addition, sectors of the model can be used to simulate nitrogen dynamics and thereby evaluate the balance of carbon dioxide, methane and nitrous oxide in Prairie wetlands.

Other wetland models include carbon accumulation models used to simulate millennial scale variations in peat accumulation in ombrotrophic peatlands, and processed based models for simulating carbon dynamics, and hence, short-term fluxes in CO_2 and CH_4. The latter are in their early stages of development, and cannot as yet deal adequately with all wetland systems, with sensitivities to land-use change or the nitrogen cycle. There is also a need for an intermediate scale model that is capable of interpolating between short-term and millennial scale processes to simulate those taking place at decadal and centennial scales. Integration of the available models and development of new models where appropriate are critical steps in developing a better understanding of wetland carbon dynamics on a local, regional and national basis.

6.5 Information and Research Priorities

Two key priorities for early action with respect to wetlands greenhouse gas flux research, therefore, are to:

- properly assess our current state of knowledge, through focused workshops, of the 'policy relevant science' with respect to consideration of wetlands management as potential sinks for inclusion in subsequent modifications to the Kyoto Protocol; and
- develop a central focus for related research in Canada, perhaps through a wetlands research node under the BIOCAP program of Canadian universities.

These early initiatives should in turn be used to develop recommendations with respect to research priorities to address the following relevant data and knowledge gaps:

- Relationships between agricultural, forestry and wetland ecosystems are not well defined or understood and need further study. Many forest and agricultural landscapes include wetlands that would be affected by measures to sequester carbon. Riparian zones often buffer wetland and other terrestrial ecosystems, while ground water and streams import and export dissolved carbon into and out of such ecosystems. Hence, while measures for carbon sequestration will focus on a specific ecosystem, the impact of such measures must be assessed in a holistic, total carbon approach to be credible and verifiable. More research on these relationships and on the transport of carbon between these components is needed.

- Research is needed on long-term carbon storage in Canadian wetlands. This could be done by collecting short cores of sediments from a set of wetlands representing the various wetland classes, states of degradation (i.e. pristine vs. farmed) and geographic regions of the country. Stratigraphic analyses of these cores of organic matter, bulk density, dry weight, chlorophyll content, dating, etc. need to be done, as a way of establishing baseline carbon storage levels in wetlands in Canada, including lakes and other open water bodies.

- A wetland restoration pilot project on a "typical" wetland needs to be undertaken, with appropriate before, during, and after measurements of: soil organic carbon (cores), emissions of CO_2, CH_4, and N_2O, rates of nitrification/denitrification, rates or biomass of methanogenic vs. methanotrophic bacteria, annual rate of primary productivity (for terrestrial and all algal components), net ecosystem biomass, levels of inorganic nutrients, hydrologic regime, etc. These measurements need to be taken in the deep water zone, the shallow emergent macrophyte zone, the riparian zone and the adjacent uplands for comparison purposes.

- A project comparing the differences in methanogenesis between different wetland types would be enlightening, looking at rates and biomass of methanogenic vs. methanotrophic bacteria, emissions of CH_4 from the different wetland types and the specific role of benthic algae in methane oxidation.

- A project looking specifically at the impact of nitrogen loading to different wetland types and the effect on N_2O emissions should be undertaken: look at both ammonium and nitrate fertilization, rates of nitrification, denitrification and N_2O emission, and assess whether the presence or absence of algal biomass has any effect on decreasing gaseous emissions.

- Long-term monitoring of wetlands across Canada is essential to all aspects of their conservation and sustainable use. Monitoring is an imperative prerequisite to the understanding, protection and enhancement of wetland ecosystems as carbon sinks.

- As mentioned in the previous section, integration of available models and development of new ones where appropriate. The latter should include a process and bookkeeping model to simulate land-use impact and natural variability in wetlands, as well as process models that include applications in non-ombrotrophic systems (site specific hydrology). Among other things, these models should be used to assess the response of abiotic factors to changes in climate.

6.6 Conclusions and Recommendations

The issue of wetlands is a unique one. The current state of scientific knowledge does not warrant considering wetlands as distinct carbon sinks under the Kyoto Protocol at this point in time. Since many wetland basins in agricultural landscapes are utilized as agricultural soils, it is impossible to differentiate one from the other. Therefore, some "utilized" wetland basins may well be a part of the Kyoto accounting system already. The same may apply to wetlands in the forestry landscapes.

Conservation of both peatlands and southern wetlands is warranted by their present ability to sequester carbon, and the fact that they tend to shift to net sources of greenhouse gases when perturbed by land-use change such as drainage for agriculture or forestry. The capacity for increased carbon storage in restored wetlands may be possible on a time-scale of years to decades. Therefore, restoration of wetlands should be considered as a part of the effort to increase carbon sinks in agricultural and forest landscapes. Attributes of wetlands which may render them net sinks include:

1) high primary productivity which ensures abundant organic carbon available for sequestration;
2) reduced decomposition due to the anaerobic nature of wetland sediments and the colder temperatures of our northern latitudes;
3) ability of pristine wetlands to store twice as much carbon as farmed wetlands;
4) reduced methane emissions due to methane oxidation in the aerobic environment provided by algae and emergent vegetation; and
5) low nitrous oxide emissions due to continually water-logged soils and low nitrate levels in many wetlands.

If Canadian wetlands are to maintain their function as active sinks and long-term storage reservoirs for carbon, it is essential to prevent continued loss and conversion of these wetlands to other uses. Wetlands degraded through direct human activities and/or climate change impacts would have a negative impact on Canada's Kyoto Protocol commitment. Conservation-positive policies and programs are required that recognize the full spectrum of intrinsic values of wetlands, including the dimension of carbon sequestration. To be meaningful in terms of climate change, these policies and programs must not only protect existing wetlands, but through restoration and enhancement of degraded wetlands, they should result in a net gain in wetland area and function for Canada. Potential credits for carbon sink enhancement under the Kyoto Protocol would provide value-added incentives for Canadian and global wetland conservation policies and programs. Such an approach would exemplify and strengthen the sustainable development underpinnings of the FCCC and the Kyoto Protocol.

Recommendation 6.1: Continue to consider wetlands as a potential Kyoto sink, in particular through the organization and coordination of science and policies relevant to such sinks.

Recommendation 6.2: Develop a central focus for related research in Canada to properly assess, through focused workshops, the current state of knowledge and research priorities relevant to wetlands management as potential carbon sinks. One option for achieving this goal is to establish a wetlands research node under the BIOCAP program of Canadian universities.

7. CARBON SEQUESTRATION IN THE KYOTO MECHANISMS AND OTHER POTENTIAL CREDITING AND TRADING MECHANISMS

7.1 Activities Implemented Jointly and The Kyoto Mechanisms

7.1.1 Background

Both the UNFCCC and the Kyoto Protocol include mechanisms that permit the use of joint (i.e. multilateral) activities to achieve national GHG mitigation goals. However, the treatment of sink activities is not consistent across mechanisms, nor is it *a priori* consistent between the mechanisms and qualifying domestic actions.

Under the UNFCCC, joint GHG mitigation activities are being undertaken through the Activities Implemented Jointly (AIJ) pilot phase of Joint Implementation. The AIJ pilot phase enables Parties to undertake cooperative efforts to reduce emissions by sources and enhance removals by sinks. No restrictions have been placed on the types of GHG sinks and reservoirs that can be enhanced by AIJ projects, and no uniform guidelines have been prescribed for the estimation of GHG benefits produced by AIJ projects. As a result, AIJ projects involving forest and agricultural sinks have varied greatly with regard to the carbon stocks evaluated (i.e. above- and below-ground biomass, soil and wood products) and the methods used for evaluating these stocks. Moreover, there has been no assurance of consistency in GHG accounting methods between national inventories and AIJ projects. However, the need for such consistency has not been considered a key issue because, according to Decision 5/CP.1, which launched the AIJ pilot phase, no credits were to accrue to any Party as a result of GHG emissions reduced or sequestered during the AIJ pilot phase. The pilot phase, which was supposed to end by CoP5, may continue beyond 2000 because Parties are divided on its need and usefulness. In particular, some consider that AIJ is now superseded by CDM and is, therefore, obsolete.

Under the Kyoto Protocol, joint GHG mitigation activities may be undertaken through the three cooperative Kyoto Mechanisms: Annex I Joint Implementation (JI), the Clean Development Mechanism (CDM) and International Emissions Trading (IET).

- Annex I JI, outlined in Article 6, enables Annex I Parties to transfer to, or acquire from, other Annex I Parties the emission reduction units (ERUs) produced by GHG mitigation projects that are additional to any that would otherwise occur. ERUs traded from one Annex I Party to a second Annex I Party must be subtracted from the assigned amount of the first Party. ERUs cannot be awarded for projects prior to 2008.

- The CDM, outlined in Article 12, enables developing countries (i.e. countries outside of Annex I) to host projects that contribute to their sustainable development goals and reduce GHG emissions, and to trade the resulting certified emission reductions (CERs) to Annex I Parties. Annex I Parties can then use the CERs to meet a portion of their target. Like Annex I JI projects, CDM projects must be additional to any that would otherwise occur. CERs can be awarded for projects starting in the year 2000. CDM projects should generate "real, measurable and long-term benefits," a criteria which, as will be seen below, raises issues for the potential treatment of sinks.

- IET, outlined in Article 17, enables Annex I Parties to trade emissions amongst themselves for the purposes of fulfilling Article 3 commitments (targets). These parts of assigned amounts, often referred to as Assigned Amount Units (AAUs), are subtracted from the Assigned Amount of the Party that is selling the AAUs and added to the one buying them.

Whereas Annex I JI and the CDM are project-based mechanisms, IET is an inventory-based mechanism. However, the emission reductions transferred among Annex I Parties through *both* Annex I JI and IET ultimately are reflected in the national inventories of Annex I Parties, and are bound by the target, because they involve the trading of parts of the assigned amounts. Non-Annex I Parties hosting CDM projects do not have a target that limits the CERs that may be transferred to Annex I Parties. All three Kyoto Mechanisms are bound by a supplementarity requirement; the acquisition of ERUs, CERs or AAUs by an Annex I Party must be supplemental to domestic actions. Although supplementarity has not yet been defined, it is generally understood to mean that an Annex I Party cannot attain its target solely through the use of the Kyoto Mechanisms.

Apart from the way sinks might be treated in these mechanisms, which is discussed in section 7.2, a key issue that has been the focus of recent debate is whether the supplementarity requirement in Articles 6, 12 and 17 should be translated into a quantitative cap on the use of the Kyoto Mechanisms by Annex I Parties. The European Union (EU) issued a proposal to impose a "concrete ceiling" on the Kyoto Mechanisms in the form of restrictions on both the sale and purchase of ERUs, CERs, and AAUs by Annex I Parties. The EU suggested that "buyer" countries could define their cap using the higher amount generated by one of two formulas. Buyer countries could raise this cap if they domestically surpass the emission reductions required by the target. In this case, they could increase their cap by the difference between the domestic reductions and the cap. The EU suggested that Annex I "seller" countries could sell no more than the amount calculated using the formula. According to the IEA, the average percentage reduction in this gap in Canada would be 34%, and in the United States would be 33%. This proposal has been criticised by many Parties, including Canada, the United States, the Russian Federation, Norway, Australia and New Zealand (IEA, 1999).

Extensive negotiations will be required before Annex I JI, the CDM and IET can be put in operation. While non-Annex I Parties have recommended that the CDM be the initial focus of attention by the FCCC, since the CDM could start as early as the year 2000, Annex I share the view that all three of the Kyoto Mechanisms be considered simultaneously to ensure their consistency and effectiveness.

In Canada, the Kyoto Mechanisms Table of the National Climate Change Process has focussed on the assessment of policy issues relating to the further development and implementation of Annex I JI, the CDM and IET. Their analyses have addressed a number of issues, none of which are specific to sinks: project additionality and baselines for Annex I JI and CDM projects; supply and demand factors influencing the use of Annex I JI and the CDM by Canadian entities; systems of accountability for emission reductions from Annex I JI and CDM projects; and design options for IET.

7.1.2 Eligibility of Sinks in Kyoto Mechanisms

Each of the Kyoto Mechanisms appears to place different restrictions on the use of sinks.

Article 17, which outlines IET, does not explicitly address sink issues. However, emission reductions traded under IET are inventory based (pieces of assigned amounts) and, therefore, face the constraints identified in Article 3. The boundaries of the Kyoto Forest will affect the supply of Assigned Amount Units (AAUs) that may be traded internationally under Article 17. These boundaries (i.e. which activities and which carbon stocks are to be included in the Kyoto Forest) will determine both what AAUs Canada will have to sell to other Annex I countries and what AAUs will be available for Canada to buy from other Annex I countries.

According to Article 6, Annex I JI projects may involve the reduction of human-induced emissions by sources or the enhancement of human-induced removals by sinks of GHGs in all sectors. Therefore, Annex I JI projects do not seem to be explicitly constrained by the limitations on sink activities specified in Article 3. However, if the restrictions on LULUCF under Article 3 do not apply to Annex I JI projects undertaken through Article 6, then it appears possible for Annex I Parties to claim GHG benefits for LULUCF activities undertaken outside of their borders that would not qualify if they were undertaken within their borders. Because each Party that sells ERUs generated through Annex I JI projects must then subtract those ERUs from its assigned amount, there may be very little incentive for an Annex I Party to host an Annex I JI project whose activities do not meet the requirements under Article 3.3 if it is not additional to what would have otherwise occurred.

Article 12, which outlines the CDM, refers only to projects involving emission reductions and does not explicitly address the inclusion or exclusion of projects involving sinks. Some Parties have interpreted the reference to "emission reductions" in Article 12 to exclude all sink projects, whereas others have argued that forest preservation projects *are* emission reduction projects. Some Parties feel that the CDM will be placed at a competitive disadvantage relative to Annex I JI if sink projects are disallowed from the CDM. The European Community stated that "Article 12 does not provide for projects for the enhancement of removals by sinks to assist Annex I Parties in achieving compliance with their commitments under Article 3, although the Conference of the Parties acting as the Meeting of the Parties to the Protocol could decide otherwise" (Austria, 1998). In non-papers addressing Articles 6 and 12, Japan stated that Article 6 projects providing an enhancement of removals by sinks should be consistent with Article 3.3 and 3.4 of the Protocol, and that the CDM should include sink projects (Japan 1998a, 1998b). In a non-paper on the CDM submitted by Australia, Canada, Iceland, Japan, New Zealand, Norway, the Russian Federation, Ukraine, and the U.S.A., the scope of

projects for the CDM was proposed to include "reductions and removals" of GHGs (Australia *et al.*, 1999). In a paper submitted on behalf of the African Group, Uganda stated simply that forestry and agricultural projects should be included in the CDM without clarifying whether these projects should involve sinks (Uganda, 1998). South Africa and Argentina explicitly supported the inclusion of sink projects in the CDM, as would some forest African countries, whereas other G77 countries, such as Small Islands States, generally oppose it.

Some Parties have indicated that the potential for loss or displacement of benefits and other risk factors associated with sink projects would outweigh the benefits. These issues are further discussed in Section 7.3, along with methodological and accounting questions.

In concluding, the options for incorporating sinks into the CDM include the following: allowing whichever sink activities qualify under Articles 3.3 and 3.4; allowing whichever sink activities qualify under Article 6 (which might mean the same); or allowing any project, including forest enhancement or preservation projects (sustainable forest management, etc.).

7.2 Possible Domestic Early Action Crediting and Emissions Trading Regimes

7.2.1 Credit for Early Action

Recognizing that current growth rates of national emissions will make attainment of its target difficult, some countries like Canada and the U.S. have been evaluating the possible benefits of a domestic early action credit program. Such a program could provide some entities with credits for GHG reductions achieved prior to the effective date of mandatory controls on GHG emissions; the credits could then be applied by those entities toward achieving compliance with any future domestic GHG regulatory program. In the end, however, the form, the value, the timeframe and the use of the so-called "credits" are the bottom line issues, and are still unresolved. By providing incentives for entities to begin reducing emissions early, such a program could ease the transition to a carbon-constrained future, and avoid abrupt adjustments to reduction obligations in 2008, which could seriously disrupt the national economy. Both Canada and the U.S. are evaluating the numerous and complex legal, policy and technical issues associated with designing and implementing a credit for the early action program.

Of particular concern — and subject to controversy — is the potential impact of an early action credit program once domestic regulation begins. Because the Kyoto Protocol does not give international credit for reductions achieved prior to 2008 (with the exception of CDM-type credits), early-action credits will have to come out of that country's assigned amount (i.e. emission budget), assuming "credits" are in the form of a GHG unit (CO_2 eq) for the first commitment period. Simply put, if a country is giving away emissions "credits" in advance of 2008 through an early-action crediting program, it would make it more difficult for the country to reach the Kyoto target during the commitment period, and in effect, raises the target during the first commitment period.

7.2.2 Domestic Emissions Trading

Several Parties have also been considering the possible benefits of establishing domestic emissions trading programs to help achieve domestic GHG reduction targets. The principle underlying an emissions trading program is that it can reduce the cost of meeting a reduction objective by encouraging reduction in an economically efficient manner. Entities facing high emission reduction costs would be able to purchase emission permits from entities that can achieve reductions at lower costs. By allowing entities the flexibility to choose whether it would be more economically efficient for them to reduce their own emissions, or purchase emission permits from another entity, a trading system can achieve overall emission reductions at the lowest economic cost. An emissions trading program can be a cap and trade system (regulatory), based on parts of assigned amounts and linked to the inventory and/or be project based and allow for the creation of credits below a certain emissions baseline. The Canadian Greenhouse Gas Reduction Trading (GERT) Pilot is an example of a trading program that creates credits from a certain baseline. GERT allows for sink projects and currently has one sink-based trade (the Forest-Based Carbon Offset Project, see Case Study 1) under review. Larger stationary sources, conversely, could be more efficiently addressed by a cap and trade regime. The SO_2 trading program in the United States is an example of such a cap-and-trade emissions trading program.

The mandate of Canada's national Tradeable Permits Working Group is to evaluate options for a mandatory permit trading program for at least some sources of GHGs. To date, this group has focussed primarily on how a mandatory tradeable permits approach might be designed and implemented as a means of *reducing* GHG emissions. Sinks have not been explicitly addressed, except in the context of including them through the voluntary arm of a hybrid approach.

7.2.3 Treatment of Sinks in Domestic Early Action Crediting and Emissions Trading

For domestic purposes, if a Party decides to allow a broader coverage of domestic trading regime than Article 3 LULUCF activities, it would be giving away credits to a non "Kyoto-eligible" activity. The same could apply to credit for early action.

Regarding domestic emissions trading, *a priori*, Kyoto sinks would be best covered under a credit creation, project-based system, as would small GHG sources. However, it appears that sinks could also be addressed under a cap and trade system, but only if monitoring is sufficiently strict and there is a legal link to a responsible entity identified in the national GHG inventory. Given the peculiar way sinks are accounted for in the Kyoto target, this option will deserve more consideration before it could be implemented.

Until afforestation, reforestation and deforestation have been defined and the qualifying carbon stocks specified, Annex I Parties, as well as private entities within Annex I countries, are likely to hesitate to undertake domestic sink projects (i.e. afforestation and reforestation projects). Because growth rates of trees generally follow an "S" curve, delays in implementing such projects will translate into lower carbon benefits during the first commitment period than would have occurred had the tree planting activities been initiated earlier.

In its May 1999 report, the National Credit for Early Action Table (Credit for Early Action Table, 1999) states that "biological sinks should be included in early action crediting." However, "...no decisions should be taken on what sinks are eligible for credit until both the IPCC and the Kyoto Protocol processes have clarified the definitions and methodologies associated with eligible sink activities." In general, certified CDM and JI reductions should be included in the CEA system, but further work is required to make recommendations on legal, implementation and design issues.

7.3 Accounting and Methodological Issues

7.3.1 Baseline, Leakage and Permanence Issues

As discussed above, the scope of sink activities that may be undertaken for the purpose of domestic early-action crediting, domestic trading, IET and perhaps Annex 1 JI, are bound by the terms of Article 3. As noted in earlier chapters though, all of the terms in Article 3 have yet to be defined.

However, the evaluation of project-based measures undertaken domestically for early action crediting and domestic trading, or internationally through Annex I JI and the CDM, involves terminology that falls beyond the scope of Article 3. Two key terms relating to project-based measures are "baselines" and "leakage."

1. A project baseline is defined as the emissions that would have occurred in the absence of the project. Adequate baseline determination is critical in addressing the additionality criteria, as only the net difference in emissions or removals as the result of the project should be eligible for credit creation. For example, when awarding credit to a forest enhancement project, the increase in carbon stock from the project should be reduced by the amount that would have regenerated naturally in the absence of the project.

2. Leakage is defined as the indirect GHG emissions or stock losses beyond the project boundary that occur as a result of the project. For example, protecting one area of forest that is expected to be deforested may result in deforestation elsewhere. Similarly, planting trees on existing cropland may cause deforestation elsewhere to grow replacement crops. Leakage is particularly problematic for land-use change projects because of constraints on land availability for most countries.

Leakage might not be so much an issue within or between Annex 1 parties because they do have targets. But for CDM projects which are hosted in non-Annex 1 countries, the benefits to the atmosphere might be lost should the displacement of a source of emissions occur.

The GHG benefits from sink projects (whether undertaken domestically or through Annex I JI or the CDM) may involve a higher degree of uncertainty and a lower degree of permanence than those from non-sink projects. Indeed, one of the most important risks associated with projects involving sinks is the fact that the GHG benefits that have been gained from such projects may be lost. This issue is often referred to as "permanence." Carbon that is sequestered through vegetation growth, or that accumulates in soils, can be lost if the vegetation burns or is allowed to decay, or if the soils are managed in such a way that the soil carbon stocks are depleted. The benefits of forest protection projects (i.e. avoided emissions from avoided deforestation) may not be permanent either because the carbon stocks of the protected forest can be depleted through human encroachment (e.g. illegal clearing and logging) and natural causes (e.g. lightning-induced fire). The possible impermanence of both types of sink projects distinguishes them from GHG reduction projects in other sectors, in which reduced or avoided emissions are permanently reduced or avoided. If project benefits of sink projects are lost, who is liable? The seller, the buyer or some sort of clearinghouse?

Project duration is a key determinant in the evaluation of real long-term benefits: legal contracts establishing commercial agreements do not last forever nor is it feasible to require that land be tied up in a certain use forever.

Another issue that will have to be assessed is the implication of allowing activities whose carbon benefits result from avoided deforestation. Forest preservation projects for GHG mitigation, whereby a proponent is claiming that the forest would have otherwise been deforested, raises two important questions regarding the timing of benefits and the potential leakage of benefits. If a forest preservation project is preventing deforestation that could have occurred over a long and uncertain period of time, such as decades, at what rate should credit be awarded to the project developer? When GHG accounting is done on a project-by-project basis, how can one ensure that a project to preserve forest in one area is not simply displacing deforestation activities to another area? This is also what the additionality criteria is supposed to avoid. If this project results in deforestation elsewhere in an Annex 1 country, this deforestation would appear in the national inventory of that Party and count against its target. In the case of CDM, it would not show in any inventory.

All of these questions have important implications for the measurement of stocks and flux associated with sink projects. Some accounting (or discounting) practices have been discussed that make carbon sequestered by sinks more similar in nature to GHG emission reductions and/or strive to address these risks. Section 7.3.2 elaborates on these possible practices.

7.3.2 Measurement/Estimates and Accounting of Carbon Stocks and Fluxes

To ensure the fungibility of emission reductions achieved by sink projects, with those from non-sink projects, or amongst different mechanisms or programs, special methods may be needed for measuring, monitoring, verifying and/or certifying emission reductions and carbon sequestration from sink projects.

Two basic kinds of accounting systems are needed for estimating carbon stocks and fluxes associated with sink activities under the Kyoto Protocol: national inventory accounting systems and project-based accounting systems. National inventory accounting systems are needed to demonstrate national attainment of the target and to determine the extent to which Parties may engage in international trading of AAUs under Article 17. Project-based accounting systems are needed in order to estimate the emission reductions achieved by: domestic GHG mitigation projects undertaken for the purpose of credit for early action and domestic trading; and international GHG mitigation projects undertaken through Annex I JI and the CDM. The development of effective national inventory accounting systems that correctly capture the Kyoto Forest, and any additional 3.4 activity, is the focus of Chapter 5 of this paper. However, an issue that deserves special consideration in this chapter is how to ensure sufficient consistency in accounting methods between national inventories and sink projects.

In project-based accounting systems, the annual net carbon benefits of sink projects may be calculated using either a stock or flux approach. For example, an agricultural soil carbon project may utilize periodic measurements of soil carbon stocks to estimate the amount of soil carbon that accumulates over a specific period of time (see, for example, Case Study 3: the Saskatchewan Soil Enhancement Project). A forest plantation project, however, may utilize either a stock approach through direct measurements (i.e. tree measurements from which volumes and then carbon stocks are estimated) or a derived flux approach using yield curves (i.e. through standard estimates of annual growth from which annual sequestration is estimated). Generally, flux approaches to project-level accounting utilise derived, rather than directly measured, fluxes.

National inventory and project-based accounting systems may use different approaches for evaluating the possible carbon stocks: above-ground biomass, litter, root biomass, soils, wood products, and landfill storage. At the national level, carbon stocks may be estimated using some combination of field measurements (using either allometric equations or destructive sampling), remote sensing and modeling. Below-ground biomass, soil carbon, wood product stocks and landfill storage typically are modeled based on above-ground biomass data collected using remote sensing, field measurements and harvesting statistics. However, at the project level: above-ground biomass is often estimated using species-dependent biomass regression equations relating biomass to measured dimensions of the trees; root biomass is often estimated using a relationship to above-ground biomass; litter biomass can be sampled directly; soil biomass can be sampled directly (if it is measured at all); wood product storage is modeled using decay rates developed on a national level; and landfill storage can be modeled using decay rates developed on a national level.

Whereas the large scale of national inventory accounting systems may preclude the direct measurement of carbon stocks and involve a high level of uncertainty, smaller-scale projects can permit the more direct measurement of some carbon stocks. However, the estimation of net changes in wood product pools and landfill storage may be more accurate at the national level than at the project level. For examples of which carbon stocks are being evaluated by current Canadian sink projects, refer to Case Study 1 on the Forest-Based Carbon Offset Project and Case Study 2 on the Soil Enhancement Project, both in Saskatchewan.

Unlike national inventory accounting systems, project-level accounting systems without a cap require the development of project baselines representing "business as usual" (i.e. the course of events in the absence of the project). This holds true for both domestic projects and international projects. In both cases, project developers need a baseline not only to measure the carbon benefits of their project relative to "business as usual," but also to demonstrate that the benefits of their project would not have occurred under "business as usual." A variety of approaches may be used to develop project baselines. Baselines can be developed using historical, current or forward-looking data. They can be established at the multinational, national, regional or project level. They can be either fixed or changeable during the course of the project lifetime. Because baselines represent a hypothetical course of events that will never occur, it can be very difficult for a project developer to create a credible baseline and for an auditor to verify that the baseline is appropriate.

Determining the baseline for sinks, especially forestry projects, can be particularly complicated. The number and complexity of the socio-economic drivers of land-use and land-use change activities make predictions uncertain. Also, forest sink projects typically have long lifetimes, sometimes several to many decades long, which mean that predictions quite far into the future are required. For example, to develop the baseline for a forest preservation project, one would need to estimate at what rate the forest would have been cleared in the absence of the project. If historical or current trends in deforestation were expected to continue into the future, then one could project the rate of deforestation using historical and current data. However, if the future deforestation rate was expected to follow a new trend as a result of factors such as population growth, changes in the markets for timber and agricultural products and natural disasters (e.g. fires, severe storms and pests), then the extrapolation of past trends into the future would not produce a credible baseline. In this case, the cumulative impact of these factors could be modeled to create a baseline. For a brief discussion of carbon accounting methods used in an AIJ forest preservation project, refer to Case Study 4 on Costa Rica's Protected Areas Project.

Undetected leakage could also contribute to discrepancies between how projects are awarded credit and how the results of projects are reflected in national inventories. As discussed above, the benefits of a project to preserve, conserve or regenerate carbon stocks in one area can be offset if the pressures that would have resulted in the loss of these carbon stocks are simply displaced to other areas outside of the project. For example, if a project to afforest degraded

agricultural land in one region of Canada results in increased forest conversion for agriculture in a different area, then the project's net benefits will not be reflected in the national inventory. Leakage can occur locally, regionally, nationally or internationally and can be very difficult to detect and measure. Options for addressing the liabilities associated with leakage include assigning a discount rate of some kind to sink projects to compensate for undetected leakage, initiating activities to reduce the potential for leakage and establishing monitoring activities to improve the detection and measurement of leakage. For examples of strategies for addressing leakage, refer to Case Study 2 on the Sierra Gorda Biosphere Reserve Project in Mexico and Case Study 4 on the Protected Areas Project in Costa Rica.

An issue that is valid both at the national level, as noted in Chapter 3 and at the project level is the accounting procedures to credit carbon benefits from projects with period harvest and replanting or regeneration. Two methods have been suggested: the "real time" method and the average standing biomass method. In the former, debits for harvest have to be accounted as they occur and, therefore, covered one way or another. In the latter, projects would receive credits up to the average increase in biomass carbon in the stand (LeBlanc, 1999). Accounting of stored carbon in wood products is a related issue.

All carbon pools (above- and below-ground, soil, litter, wood products) do not necessarily have to be counted in a project. The size of the pool, the rate of change and direction of change are factors. If the change in direction in a pool is negative (i.e. the pool is becoming a source), then it must be measured. Similarly, if the changes are large or fast, then they must be measured. Transaction costs can be reduced by developing rules allowing the investor to determine if getting additional C credits is worth the measurement costs (LeBlanc, 1999).

One proposal discussed by Canada's Credit for Early Action Table that has particular relevance to sink projects is the use of a bounty schedule. "A bounty schedule is a limited set of 'creditable actions', each with a specific quantification protocol or factor, that is used to assign credits to actions (projects or activities), not to actual emission reductions." A bounty schedule may be a convenient way to assign credits to carbon sequestration projects and forest protection projects, although the great variability in carbon sequestration rates among different climatic regimes and management systems — and the uncertainties in projecting deforestation rates — could make design of the protocols a complex process.

Experience under AIJ indicates that sellers have, in general, addressed the permanence issue through project design. For example, forest protection projects may involve forest management measures to protect against fire and illegal logging. Another approach that has been used has been to hold back some portion of the total carbon benefits as a buffer against loss of the remaining carbon stores. This could be in the form of a portion of the land areas within the project (see the Protected Areas Project in Case Study 4), in which case, the carbon on the reserved areas could be used as a replacement if some of the carbon in the primary area is lost, either through human or natural causes. This could also be in the form of a carbon stock component, or components, on the entire project area (see the Sierra Gorda Biosphere Reserve Project in Case Study 2). In this case, the reserved carbon components could be used if some of the primary carbon is lost. Ultimately, however, there can be no guarantee that carbon stored in biotic pools will remain stored forever.

Another option suggests that minimums may be established for the number of years that stored carbon must remain stored for it to be deemed "permanent" (e.g. 50 years). Another example is the concept of tonne-years. In a recent paper, it has been suggested that the effect on radiative forcing from one tonne of carbon dioxide removed from the atmosphere and stored for 55 years may be considered equivalent to the effect of one tonne of carbon emitted from fossil fuel combustion (Moura and Wilson, in press). At this time, there is no agreed-upon convention.

These accounting issues point to the need to develop standard GHG accounting guidelines for sink projects in order to avoid discrepancies between the way project benefits are estimated by project developers and the way those benefits are reflected in the national inventory, if necessary.

When developing guidelines for project-based GHG accounting, Parties can draw on the experience gained during the AIJ pilot phase. Of the 95 AIJ projects officially recognized by the UNFCCC Secretariat as of October 1998, 14 are categorized as land-use change and forestry or agriculture projects. Of these projects, eleven involve forest preservation, reforestation or restoration; one involves afforestation; one involves agroforestry; and one involves agricultural soil carbon accumulation. Only three of these projects are hosted by transition countries; two are hosted by

the Russian Federation and one by the Czech Republic. These 14 projects are co-sponsored by only three Annex I investor Parties: the Netherlands, Poland and the United States (UNFCCC, 1998). However, additional Parties are providing technical assistance and funding for these projects and additional AIJ projects in these sectors have been initiated by Parties but have not yet received official recognition. The accounting methods applied in these projects, many of which are summarized in the annual reporting documents submitted to the UNFCCC Secretariat, provide a useful starting point for developing project-level accounting guidelines for sink projects initiated under the Kyoto Protocol (U.S. EPA, 1998).

7.4 Sink Projects and Sustainable Development

One of the key reasons for including sink projects in domestic GHG mitigation efforts, as well as Annex I JI and the CDM, is that, in addition to providing GHG benefits, the protection and enhancement of carbon sinks and reservoirs is considered an integral element of sustainable development for most Parties. Both Annex I and non-Annex I Parties recognize that activities such as forest preservation, afforestation, reforestation, reduced-impact logging and agricultural soil carbon conservation offer cost-effective means to offset CO_2 emissions, ensure the long-term productivity of forest and agricultural resources and generate important ancillary benefits such as watershed protection, biodiversity conservation and reduced desertification. Particularly in some developing countries where land-use and economic pressures are resulting in accelerated deforestation, international investments in sink projects for GHG mitigation may constitute a critical financial incentive to use dwindling forest resources in a sustainable manner. Because CDM projects are intended to further the sustainable development goals of the host country government, some Parties have argued that host countries should have the option to implement sink projects under Article 12.

Some developing countries, however, fear that forestry offset projects may conflict with national sovereignty or control over critical natural resources. Further, long duration of these projects could dictate land-use patterns for decades. Finally, there is the fear that non-sustainable projects, such as plantations of fast growing species, would adversely impact biodiversity.

As noted previously, the eligibility of sink projects under Article 6 and Article 12 will affect the international supply of ERUs (Annex I JI) and CERs (CDM) that may be acquired by Canada. If sinks are included in the CDM, if the coverage in JI and the CDM is broad (i.e. all biomass and soil components are counted, including forest protection projects) and if measurement, monitoring, verification and/or certification requirements are not too onerous, there is likely to be significant interest in developing sink projects in other countries. The relatively high carbon sequestration rates and relatively low land and labour costs in many developing countries (and possibly some transition countries) are likely to make sink projects particularly attractive to investors.

One counter argument to the use of sink projects for GHG mitigation is that the potentially enormous supply of relatively inexpensive credits from sink projects particularly in developing countries could provide a disincentive for Annex I Parties to make more expensive reductions in energy-sector emissions. In the context of the Kyoto Protocol, there could potentially be a trade-off between promoting sustainable use of forest and agricultural resources on one hand and sustainable use of energy resources on the other hand. A second concern that has been raised is that afforestation projects involving plantation establishment could actually be detrimental to biodiversity. Some Parties have warned that loopholes in the Kyoto Protocol could potentially encourage plantation establishment involving monocultures of commercial species at the expense of native forest, thereby reducing the biodiversity of both flora and fauna.

CDM projects involving timber production could have a substantial impact on the international trade of timber and timber products. Projects involving sustainable harvesting, afforestation and reforestation, or even preservation, could increase the supply of timber from developing countries. Annex I Parties that export timber, such as Canada, should carefully evaluate these potential market changes.

7.5 Conclusions and Case Studies

In conclusion, important decisions have yet to be made internationally relating to the treatment of sinks and sink projects under the Kyoto Protocol. These decisions will impact the implementation of Annex I JI, the CDM and IET, as well as the establishment of domestic early-action crediting and domestic trading regimes.

Some key questions to be resolved include the following:

1. Are sink projects undertaken through Annex I JI (Article 6) constrained by Articles 3.3 and 3.4?

2. Should sink projects be included under the CDM (Article 12)? If so, should they be constrained by Articles 3.3 and 3.4 and/or be consistent with Article 6 or include any project?

3. How can baselines, additionality, leakage and permanence issues be addressed in project requirements and design to minimize loss of benefits and transaction costs?

4. In light of the current uncertainties regarding Article 3, how should Annex I Parties determine which domestic sink projects could be credited under domestic trading and any "early-action" regimes? Should Canada award early credits for domestic sink projects that ultimately may not qualify under the Kyoto Protocol? Could the potential benefits of these projects, in terms of capacity building, engagement of key stakeholders and sustainable development, outweigh the potential cost of having to make up these credits through alternative activities if the projects ultimately do not qualify under the Kyoto Protocol?

5. To what extent are Canadian entities likely to engage directly in Annex I JI and CDM projects? Are sink projects likely to be of interest to Canadian entities? There is also a need to study the interest in domestic trades involving sequestration that has been demonstrated by the Forest-Based Carbon Offset Project currently under review with GERT (Case Study 1).

6. What lessons can be learned from existing or past AIJ sinks projects? If AIJ projects are awarded credit under the Kyoto Protocol, either under Articles 6 and 12 or some other mechanism, provisions may needed to resolve discrepancies in the treatment of sinks among AIJ, Annex I JI and the CDM.

Case Studies

Case Study 1

Title: Forest-Based Carbon Offset Project

Location: East-central Saskatchewan

Type: Reforestation and forest preservation

Mechanism: Domestic trading/credit for early action

Projected Benefits: 22,000,000 t CO_2 over 50 years (with a starting date of October 1999)

Description: In an agreement between the Forest Ecosystems Branch, Saskatchewan Environment and Resource Management and Saskatchewan Power Corporation:

- 3,333 ha of Not Sufficiently Restocked (NSR) land in east central Saskatchewan will be reforested over four years, starting October 1999.
- 178,000 ha of forest will be removed from Forest Management Agreement Areas and put into Forest Carbon Reserves.

Monitoring Plan: Above-ground biomass will be estimated every five years on fixed plots using species-specific biomass equations. Soil and litter carbon are not included.

Protection Against Leakage and Liability: Provincial forest-fire and pest management programs.

Issues:
1. Would the NSR lands have regenerated without the project (baseline)?
2. Is baseline an issue?
3. Is additionality an issue?
4. Is harvesting considered a loss of carbon stock?
5. Will the removal of harvest rights cause increased harvesting elsewhere?
6. How will this project's carbon benefits be reflected in Canada's national GHG Inventory?

Status: Under review with GERT.
(http://www.gert.org/listings/t4.html)

Case Study 2

Title: Permanent Afforestation and Protection of Forested Land in the Sierra Gorda Biosphere Reserve

Location: Central Mexico

Type: Afforestation and forest preservation

Mechanism: Clean Development Mechanism

Projected Benefits: 25,000 t CO_2 by 2010,
645,400 t CO_2 over 100 years (start date to be determined)

Description: The Joya del Hielo Land Trust, working in conjunction with the Sierra Gorda Biosphere Management NGO, will protect 600 ha of degraded agricultural lands and 600 ha of mature forest. The degraded lands will be allowed to naturally afforest.

Monitoring Plan: Above-ground and root biomass will be estimated every ten years on fixed plots using species-specific biomass equations. Soil and litter carbon will be monitored at the start of the project and measured in later years if it is needed to cover any losses or leakage.

Protection Against Leakage and Liability: Soil and litter carbon sequestration, estimated as 53% of the total carbon per hectare, will be used to cover any shortfall as a result of loss or leakage.

Issues:
1. Are sinks recognized under CDM?
2. Is natural regeneration acceptable (i.e. is this considered a human-induced activity)?
3. Will the removal of agricultural land cause deforestation elsewhere?

Status: Looking for an investor.
(http://www.woodrising.com/woodrise/offsets.htm)

Case Study 3

Title: Saskatchewan Soil Enhancement Project

Location: Saskatchewan

Type: Sustainable agricultural practices

Mechanism: Domestic trading/credit for early action

Projected Benefits: 733,000 to 1,100,000 t CO_2 per year (with a start date of 1992, lifetime uncertain)

Description: Between 1993 and 1997 the Saskatchewan Soil Conservation Association and a consortium of Canadian companies delivered educational and extension services that encouraged the adoption of direct seeding in the farming community. To date approximately three million hectares have been converted from traditional agricultural practices to direct seeding.

Monitoring Plan: Annual soil sampling and analysis

Protection Against Leakage and Liability: None published

Issues:
1. Will agricultural soils be included under Article 3 of the Kyoto Protocol?
2. Is carbon sequestration by soils measurable over a small time period?
3. Is baseline an issue?
4. Will early action be recognized?
5. Are there provisions to protect against leakage, non-permanency?

Status: Underway (and recorded as an offset in the participating companies' Action Plans).

Case Study 4

Title: Territorial and Financial Consolidation of Costa Rican National Parks and Biological Reserves (Protected Areas Project)

Location: Costa Rica

Type: Forest preservation

Mechanism: Activities implemented jointly

Projected Benefits: 57,000,000 t CO_2 over 25 years (with a starting date of January 1998)

Description: The Costa Rican Ministry of Environment and Energy, the Costa Rican National Parks Foundation and the Costa Rican and U.S. Earth Council Foundation are collaborating to register 530,500 hectares of forest and pasture as part of Costa Rica's Forest Patrimony of the State. These lands have already been declared national parks and biological reserves, but have not been registered as such for a variety of reasons, including property disputes and lack of funding for completing property transfers. Until this registration takes place, the lands will be vulnerable to deforestation or degradation. The project is claiming carbon benefits in the form of avoided deforestation in primary forest and carbon sequestration in secondary forest and pasture. In primary forest areas, the rate of deforestation assumed under the reference scenario for each parcel is based on the deforestation rate in neighbouring areas during the 13 years prior to the project, with a systematic modification to reflect the parcel's current land-tenure status. In secondary forest and pasture areas, the reference scenario consists of zero net change in carbon stocks. The project is evaluating the following carbon stocks: tree biomass, understory biomass, litter, soil organic matter and wood products. The project also involves the construction of an Earth Center: a development combining residential, commerce and work activities to promote public education, entertainment and ecotourism. The project is funded by an initial contribution from the Earth Council Foundation and the Costa Rican National Parks Foundation and by the sale of Certified Tradable Offsets (CTOs) based on the carbon benefits generated by the project. Each CTO represents one metric tonne of carbon. The sale of CTOs is managed by Centre Financial Products Ltd.

Monitoring Plan: SGS Forestry, which is accredited by the Forest Stewardship Council, developed the monitoring system and will audit the use of this system at least once per year. Monitoring activities include bi-annual field studies to estimate biomass stocks and biomass growth rates and the analysis of satellite images of the project area to be taken every three years. SGS Forestry has also developed software for monitoring carbon stocks. Monitoring will be conducted by Costa Rica's National System of Conservation Areas and the Costa Rican National Parks Foundation.

Protection Against Leakage and Liability: The Protected Areas Project is being implemented in conjunction with the Private Forestry Project, an AIJ project between Costa Rica and Norway that creates incentives for private landowners to support tree plantations and the conservation and sustainable management of natural forest in priority areas. These two projects, which target both publicly and privately held lands on a national scale, help to protect against leakage of benefits on a national level. CTOs are certified as consolidation activities occur and, therefore, represent projections of future sequestration. To guard against liability in the production of CTOs, the Protected Areas Project is reserving approximately 15% of the carbon benefits as a buffer. SGS Forestry guarantees that CTOs from the Protected Areas Project are "98% implementation risk free."

Issues: 1. Does the national-scale carbon accounting method offer an acceptable level of precision in the estimate of carbon benefits?

2. Should the same carbon accounting method be applied to all forest preservation projects in Costa Rica, including those that pre-dated the Protected Areas Project?

3. Can the Protected Areas Project be considered for inclusion in the CDM?

Status: In progress (Chacon et al, 1998; No buyers yet, 1998; U.S. Environmental Protection Agency, 1998).

8. CONCLUSION

A number of critical observations can be made from the Options Paper. The net "business as usual" contribution from reforestation, afforestation and deforestation activities from 2008-2012 could be either a substantial source or sink, depending primarily on international negotiation outcomes on definitions. These definitions are expected to be resolved, at the earliest, at CoP6 in late 2000. As a result, the net impacts of land-use, land-use change and forestry on targets in the first and subsequent commitment periods will be determined by international negotiation outcomes. Finally, because of large data gaps and basic information needs, estimates are incomplete and uncertain and, therefore, refinements and research are necessary.

As such, these conclusions are no different from the observations made in the Table's Foundation Paper. However, the work of the Table, in conjunction with the Forest Sector Table, made it clearer that sinks remain very important to Canada's interests in developing both its international negotiating strategy and in formulating the National Implementation Strategy. Land-use change and forestry could help Canada's achieve its objectives, but it also creates challenge.

Tables 8.1a summarizes the net CO_2 removals/emissions that could be associated with reforestation, afforestation and deforestation under a business as usual situation and enhanced afforestation actions. Depending on whether reforestation will be defined as re-afforestation (a change in land use) or as regeneration after harvest (no change in land use), the net RAD contribution under a business as usual scenario is estimated to range from a source of 3 to 19 Mt CO_2 or from a source of 21 Mt to a sink of 10 Mt CO_2 during the first commitment period, respectively. Estimates are not available for the second period, but if we assume that deforestation levels remain constant, the business as usual would be a source of 3 to 19 Mt or from a source of 5 Mt to a sink of 22 Mt CO_2, respectively.

The Table could not assess actions to enhance reforestation or decrease the deforestation rates, for a variety of reasons already mentioned in the Introduction and Chapter 3. Generally, the information and data are too scarce and uncertain to be able to draw meaningful estimates, if any, of effects of actions that would impact reforestation and deforestation. Assessing the sequestration potential and cost of various afforestation actions has been a major focus of the analytical work jointly undertaken by the Forest Sector and Sinks Tables. Afforestation options differ from most other options assessed by National Tables in that the benefits of a Canadian afforestation program would be relatively long term in nature. Indeed, with afforestation actions such as those assessed in this Paper, the net gain above the BAU situation presented previously would be around 2 Mt CO_2 in the first period and second period. The effect of fast-growing species plantation in the second commitment period is highly uncertain and depends on the accounting of on-site and off-site carbon from harvested trees, which has yet to be agreed upon internationally.

While afforestation has the potential to contribute to attainment of our target, its impact would remain limited during the first period given that trees would be, at most, twelve years old in 2012 if they are planted next year. Delaying action would lower the net sequestration gains expected during the accounting period, accordingly. While facing high upfront costs, the net impact of afforestation in subsequent commitment periods would be higher and for a lower per ton cost. In 2020, 2.9 Mt CO_2 per year could be sequestered from the afforestation of traditional species over the period 2001-2015 and in 2050 it could amount to 7.5 Mt CO_2. The Table recommends that immediate action be taken to put in place afforestation programs of both fast-growing and traditional species. However, planting trees on agricultural lands will clearly not be an easy task. Implementation of afforestation action faces many barriers that need to be studied and removed; and a substantial amount of planning is required.

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Table 8.1a Summary of Net CO_2 Removals/Emissions ($MtCO_2$) from Reforestation, Afforestation and Deforestation both With and Without Action

Activity	2008-2012 (Mt CO_2)	2013-2017 (Mt CO_2)	2018-2022 (Mt CO_2)
Afforestation BAU	Negl.	Negl.	Negl.
Reforestation BAU 1. Re-afforestation OR 2. Regeneration (post-harvest)[1]	 0 -2 to 13	 0 14 to 25	 0 37 to 42
Deforestation BAU	-3 to -19 [3]	N/a	N/a
NET TOTAL RAD BAU **1. Re-afforestation OR** **2. Regeneration (post-harvest)**	 **-3 to -19** **-21 to 10**	 **N/a**	 **N/a**
Afforestation Actions - Fast growing (2001-2015) - Traditional (2001…) *sub-total*	 1.3 0.8 *2.1*	 ? [2] 1.8 * *1.8*	 ? 2.9 *2.9*
Enhanced Reforestation Actions	N/a	N/a	N/a
Reduced Deforestation Actions	N/a	N/a	N/a
NET TOTAL RAD BAU+ ENHANCED ACTIONS **1. Re-afforestation OR** **2. Regeneration (post-harvest)**	**-1 to -17** **-19 to 12**	**N/a**	**N/a**

N/a: not available
BAU: Business as Usual (no new actions)
Emissions are shown with a negative sign.

1. Lower end: all carbon pools (above- and below-ground, litter and soils); upper end: above-ground only.
2. Rotation of fast-growing species is much shorter than traditional; the fate of harvested C generates accounting issues from the second commitment period.
3. Another estimate of CO_2 emissions from forest clearing ranges from 9 to 14 Mt CO_2 per year (see Chapter 3), but there is no mean to confirm that this estimate is of greater certainty.

Table 8.1b summarizes the estimates of sequestration potential from categories that are not currently recognized as potential sinks under the Kyoto Protocol, namely agricultural soils, the managed forest and conservation of wetlands basins. Estimates for the managed forest (or the forest that is commercially productive, accessible and non-reserved) are very uncertain. A closer look into the sink or source status of the managed forest is necessary to inform Canada's negotiating position for potential inclusion of further forest categories. Wetlands impacts cannot be presently assessed in terms of potential sequestration benefits. However, some wetlands riparian areas on which permanent cover could contribute to a sink, are active components of the agricultural soil landscapes and have been included in the estimates.

Table 8.1a Summary of Net CO_2 Removals/Emissions ($MtCO_2$) from Reforestation, Afforestation and Deforestation both With and Without Action

Activity	2008-2012 (Mt CO_2)	2013-2017 (Mt CO_2)	2018-2022 (Mt CO_2)
Afforestation BAU	Negl.	Negl.	Negl.
Reforestation BAU 1. Re-afforestation OR 2. Regeneration (post-harvest)[1]	 0 -2 to 13	 0 14 to 25	 0 37 to 42
Deforestation BAU	-3 to -19 [3]	N/a	N/a
NET TOTAL RAD BAU 1. **Re-afforestation OR** 2. **Regeneration (post-harvest)**	 **-3 to -19** **-21 to 10**	 **N/a**	 **N/a**
Afforestation Actions - Fast growing (2001-2015) - Traditional (2001…) *sub-total*	 1.3 0.8 *2.1*	 ? [2] 1.8 * *1.8*	 ? 2.9 *2.9*
Enhanced Reforestation Actions	N/a	N/a	N/a
Reduced Deforestation Actions	N/a	N/a	N/a
NET TOTAL RAD BAU+ ENHANCED ACTIONS 1. **Re-afforestation OR** 2. **Regeneration (post-harvest)**	 **-1 to -17** **-19 to 12**	 **N/a**	 **N/a**

N/a: not available
BAU: Business as Usual (no new actions)
Emissions are shown with a negative sign.

1. Lower end: all carbon pools (above- and below-ground, litter and soils); upper end: above-ground only.
2. Rotation of fast-growing species is much shorter than traditional; the fate of harvested C generates accounting issues from the second commitment period.
3. Another estimate of CO_2 emissions from forest clearing ranges from 9 to 14 Mt CO_2 per year (see Chapter 3), but there is no mean to confirm that this estimate is of greater certainty.

Table 8.1b summarizes the estimates of sequestration potential from categories that are not currently recognized as potential sinks under the Kyoto Protocol, namely agricultural soils, the managed forest and conservation of wetlands basins. Estimates for the managed forest (or the forest that is commercially productive, accessible and non-reserved) are very uncertain. A closer look into the sink or source status of the managed forest is necessary to inform Canada's negotiating position for potential inclusion of further forest categories. Wetlands impacts cannot be presently assessed in terms of potential sequestration benefits. However, some wetlands riparian areas on which permanent cover could contribute to a sink, are active components of the agricultural soil landscapes and have been included in the estimates.

As far as agricultural soils are concerned, the estimates of soil C sequestration potential summarized below show great differences depending on the approach and method taken. For example, some simplifying assumptions were used to come out with gross sequestration potential. Differing results are obtained with models. Further modeling work is under way and will show again different estimates. Nonetheless, there is certainty that soils have the potential to be a sink for carbon if they are managed in an adequate manner, that is, that either prevents the loss of soil organic carbon or increases the level of soil organic carbon to a new equilibrium. The estimates presented here provide an indication of what the most potentially effective practices to enhance sinks may be. Clearly, croplands have the highest potential for sequestration with the use of reduced /no-till tillage systems and reduced summerfallow.

Conservation of soils and wetlands ecosystems is warranted by their present ability to sequester carbon and the risk they become sources. Conservation and enhancement of sinks may also be done for other purposes that should not be overlooked. Impacts on other greenhouse gas emissions (fuel use, methane and nitrous oxide which are part of biological sources and sinks), have not been estimated by the Table and could potentially offset some gains for both agriculture and wetlands categories.

Table 8.1b Summary of CO_2 Sequestration Potential from Activities Not Currently Included in the Protocol

Activity/Category	2008-2012 (Mt CO_2)	2013-2017 (Mt CO_2)	2018-2022 (Mt CO_2)
Managed Forest BAU[1]	11	N/a	N/a
Agricultural Soils:			
-CENTURY model BAU (cropland)	1.6	N/a	N/a
-With incentives [2]:			
Croplands (reduced-till /no-till)	18.3	18.1	N/a
Pasture management	0.7	2.5	
Conversion marg. (land to grass)	2.2	2.2	
Wetlands riparian areas	2.9	2.9	
Sub-total [3]	*24*	*25*	
Wetlands Basins	N/a	N/a	N/a

N/a: non available
BAU: Business as Usual (no new actions)

1. If the managed forest was included, the accounting would probably be different (net/net approach as opposed to gross/net approach). A lot of uncertainties are associated with this 11 Mt estimate.
2. These are gross sequestration potential (other lands could be CO_2 sources) and do not include CH_4 and N_2O emissions impacts.
3. Totals have been rounded.

The Table had a difficult analytical task due to the high uncertainties related to the unresolved international negotiations on methodological issues related to land-use, land-use change and forestry. At present, quantitative estimates of the potential net contribution of emissions from sources and uptake from sinks for Canada can only be presented as a range of possible outcomes. Thus, the Sinks Table recommends extreme caution in trying to interpret the estimates provided in this report and using them in the national roll-up and modeling exercise.

The analysis of measures/actions provided in this report is a good start for further work. Implementation of measures in the forest and agriculture areas will best be dealt with by those sectors. Research and methodological work are recommended to better understand carbon flux processes, to improve the quality of data and emissions and removals estimates in forestry, agriculture and wetlands. Finally, the reporting requirements of sinks from land-use change and forestry cannot be fulfilled with the inventory information and models currently available in Canada. Considerable investments into research and information will be required to be able to provide, internationally, estimates of the verifiable change in carbon stocks. These initiatives need to be started as soon as possible.

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APPENDICES

Appendix A - Members of the National Sinks Table

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Appendix B – List of Studies Commissioned by the Sinks Table

ArborVitae Environmental Services Ltd., Woodrising Consulting Inc., and Peter Duinker (1999). Benefits of Afforestation Programs in Ontario, Quebec and the Atlantic Provinces. (Prepared for Sinks and Forest Sector Tables). March.

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Global Change Strategies International Inc. (GCSI) (1999). Soil Carbon Sinks Potential in Key Countries, Final Report for the National Climate Change Sinks Issue Table. Ottawa, Ontario, May. 67pp.

ICF Consulting Canada, Inc. (1999). Carbon Sequestration and the Kyoto Mechanisms and Other Potential Crediting and Trading Mechanisms. (Prepared for the Sinks Table and the Forest Sector Table). July

Jacques Whitford Environment Limited, University of Saskatchewan (1999). Report to Public Works and Government Services Canada on Assessing Options for Measuring and Monitoring Verifiable Changes in C Stocks in Agricultural Soils. (Prepared for the Sinks Table). April.

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Williams, J., and P. Griss (1999). Design and Implementation Options for a National Afforestation Program(s). ArborVitae Environmental Services Ltd. (Prepared for Sinks and Forest Sector Tables). April.

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Appendix C
Sequestration Rates for Reduced/No-Till and Reduced Summerfallow on Prairie Croplands (from McConkey *et al.*, 1999)

Reduced/No-Till

Soil Zone	**Brown/Dk Brown**	**mDB/thinBl**	**thick Black**	**Dk Grey/Grey**
Medium Texture/Mid-slope (in tonnes CO_2/ha/yr)	0.73	1.34	1.34	1.46
% Cropland by Soil Zone	(from AAFC,1988; Marie Boehm, 1999, CEEMA output)			
Alberta	24.9%	29.1%	17.4%	28.6%
Saskatchewan	40.7%	32.3%	22.0%	5.0%
Manitoba		44.0%	48.0%	8.0%

Weighted Sequestration Rates					**Provincial Rate**
Alberta	0.18	0.39	0.23	0.42	1.22
Saskatchewan	0.30	0.43	0.29	0.07	1.10
Manitoba	0.00	0.59	0.64	0.12	1.35

Proportions of cropland in each soil zone are estimated for Brown, Dark Brown and Black zones by CEEMA model.
They are reported for Brown, Dark Brown, Black and Grey in AAFC, 1988.
To convert to the soil zone categories in the Table above:

Assume for percentages:

Used CEEMA percentages for 1996.
dry Dark Brown = 0.5* Dark Brown then add to Brown
moist Dark Brown = 0.5* Dark Brown then add 0.5*Black
thin Black = 0.5* Black
thick Black = 0.5* Black
Grey = estimates from AAFC, 1988.
MB estimates scaled down to include estimates of Grey

Sequestration Rates for Reducing Summerfallow

Assume most opportunity for S-F reduction is in the Brown/dry Dark Brown soil zones.
Sequestration rate per year of S-F reduction from McConkey = 0.4 tonnes C/ha/yr (1.467 tonnes CO_2/ha/yr)
Following McConkey's methods and assuming farmers change from 1 year in 2 to 1 year in 5:

Cgain = 0.4* (.8-.5) = 0.12 Tonnes C/ha/yr
0.44 Tonnes CO_2/ha/yr

Appendix D – Soil Carbon Dioxide Sequestration Potential

	Cropland		Permanent Pastures	Degraded Lands Saline	Eroded	Irrigated Lands	Total Rate	Yearly Potential 1995-2000	Cumulative Potential 1995-2000	Yearly Potential 2000-2005	Cumulative Potential 1995-2005	Yearly Potential 2005-2010	Cumulative Potential 1995-2010	Yearly Potential 2010-2015	Cumulative Potential 1995-2015	Yearly Potential 2015-2020	Cumulative Potential 1995-2020
	Conservat. Tillage (Mt CO_2/yr)	*Increased Productivity* (Mt CO_2/yr)	*Best managt.* (Mt CO_2/yr)	*Reclamation* (Mt CO_2/yr)	*Reclamation* (Mt CO_2/yr)	*Control* (Mt CO_2/yr)	(Mt CO_2/yr)	(Mt CO_2/yr)	(Mt CO_2)	(Mt CO_2/yr)	(Mt CO_2)	(Mt CO_2/yr)	(Mt CO_2)	(Mt CO_2/yr)	(Mt CO_2)	(Mt CO_2/yr)	(Mt CO_2)
SOUTH AMERICA																	
Argentina	8.8	20.0	28.7	4.1	3.1	0.6	65.3	13.1	65.3	26.1	195.8	52.2	457.0	65.3	783.4	65.3	1,109.8
Brazil	10.2	37.1	37.5	0.4	3.9	1.1	90.2	18.0	90.2	36.1	270.6	72.2	631.4	90.2	1082.3	90.2	1,533.3
Chile	0.8	3.2	2.7	0.5	3.4	0.5	11.0	2.2	11.0	4.4	33.1	8.8	77.3	11.0	132.5	11.0	187.7
Peru	0.7	2.7	5.5	0.0	5.9	0.6	15.3	3.1	15.3	6.1	45.9	12.2	107.1	15.3	183.6	15.3	260.1
NORTH & CENTRAL AMERICA																	
Costa Rica	0.1	0.4	0.5	0.0	0.5	0.0	1.4	0.3	1.4	0.6	4.3	1.1	10.0	1.4	17.1	1.4	24.3
Mexico	4.1	18.1	15.0	0.1	8.8	2.2	48.3	9.7	48.3	19.3	145.0	38.7	338.3	48.3	579.9	48.3	821.5
Guatemala	0.3	1.3	0.5	0.0	1.0	0.0	3.2	0.6	3.2	1.3	9.5	2.5	22.2	3.2	38.1	3.2	53.9
U.S.	71.0	137.8	56.2	0.2	3.5	7.9	276.6	55.3	276.6	110.6	829.7	221.2	1,935.9	276.6	3,318.6	276.6	4,701.4
AFRICA																	
Ethiopia	2.6	10.2	9.0	1.8	2.0	0.1	24.9	5.0	24.9	10.0	74.7	19.9	174.2	24.9	298.7	24.9	423.2
Kenya	0.8	3.3	4.3	0.4	1.6	0.0	10.4	2.1	10.4	4.2	31.3	8.4	73.1	10.4	125.3	10.4	177.5
Nigeria	5.9	23.8	8.1	0.1	4.2	0.1	42.1	8.4	42.1	16.8	126.3	33.7	294.7	42.1	505.2	42.1	715.6
South Africa	2.3	9.7	16.4	0.2	8.4	0.5	37.4	7.5	37.4	15.0	112.3	30.0	262.1	37.4	449.4	37.4	636.6
ASIA																	
China	17.6	70.4	80.7	0.6	3.9	18.1	191.4	38.3	191.4	76.6	574.2	153.1	1,339.7	191.4	2,296.6	191.4	3,253.5
India	31.0	124.4	2.3	0.6	4.0	19.1	181.5	36.3	181.5	72.6	544.4	145.2	1,270.3	181.5	2,177.6	181.5	3,084.9
Indonesia	5.1	22.7	2.4	1.2	8.3	1.7	41.4	8.3	41.4	16.6	124.3	33.1	290.0	41.4	497.1	41.4	704.2
Japan	0.8	3.3	0.1	0.0	2.6	1.0	7.9	1.6	7.9	3.1	23.6	6.3	55.0	7.9	94.3	7.9	133.5
Kazakhstan	6.5	25.9	37.6	0.0	7.6	0.8	78.5	15.7	78.5	31.4	235.5	62.8	549.6	78.5	942.1	78.5	1,334.6
Thailand	3.8	15.2	0.2	0.1	2.3	1.7	23.3	4.7	23.3	9.3	69.8	18.6	162.9	23.3	279.3	23.3	395.7
Turkey	5.1	20.2	2.5	0.1	6.4	1.5	35.8	7.2	35.8	14.3	107.4	28.6	250.5	35.8	429.5	35.8	608.4
AUSTRALASIA																	
Australia	12.1	34.2	84.1	0.6	1.0	0.9	132.9	26.6	132.9	53.2	398.7	106.3	930.4	132.9	1,595.0	132.9	2,259.5
Fiji	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.1	0.3	0.1	0.9	0.2	2.0	0.3	3.4	0.3	4.8
New Zealand	1.8	2.8	2.7	0.0	0.1	0.1	7.6	1.5	7.6	3.0	22.8	6.1	53.1	7.6	91.1	7.6	129.0
EUROPE																	
Germany	4.3	8.8	1.2	0.0	0.5	0.2	15.0	3.0	15.0	6.0	44.9	12.0	104.8	15.0	179.6	15.0	254.4
Italy	4.3	8.7	1.0	0.0	0.3	1.0	15.4	3.1	15.4	6.1	46.1	12.3	107.5	15.4	184.3	15.4	261.1
Netherlands	0.3	0.7	0.3	0.0	0.0	0.2	1.5	0.3	1.5	0.6	4.4	1.2	10.3	1.5	17.7	1.5	25.1
Norway	0.3	0.7	0.0	0.0	0.0	0.0	1.0	0.2	1.0	0.4	3.1	0.8	7.3	1.0	12.5	1.0	17.7
Russia	24.4	97.7	15.7	0.0	0.6	2.0	140.4	28.1	140.4	56.2	421.3	112.3	983.0	140.4	1,685.1	140.4	2,387.3
Ukraine	6.3	25.3	1.5	0.0	0.2	1.0	34.3	6.9	34.3	13.7	102.9	27.5	240.2	34.3	411.8	34.3	583.3
United Kingdom	2.1	4.7	2.6	0.0	0.7	0.0	10.1	2.0	10.1	4.1	30.4	8.1	71.0	10.1	121.7	10.1	172.4
CANADIAN ESTIMATES Section 4.1 Options Paper*																	

1Mt = 1 million metric tonnes. Source: GCSI (1999) except Canadian estimates.*

*Options Paper, section 4.1 (gross sequestration potential, including croplands, grasslands, Prairie riparian wetlands areas and excluding eroded lands).

Appendix E - Table of Units*

Pg – petagram (10^{15} gm) = Gt (gigatonne)
Tg – teragram (10^{12} gm) = Mt (million metric tonnes)
Gg – gigagram (10^{9} gm)
Mg – megagram (10^{6} gm) = tonne (t)
kg – kilogram (10^{3} gm)
1 ha – 1 hectare = 2.471 acres = 10,000 m^2
1 square kilometre – km^2 = 100 ha
Mha – million hectares
1 mass unit carbon (C) converts to 44/12 units carbon dioxide (CO_2)
1 kg/m^2 =10t/ha
g C $/m^2/d$ = gram of C per square meter per day

* As a result of the use of varying references and sources, both of scientific and general nature, the use of units in this report is inconsistent. Results and estimates are presented in Mt CO_2 as a commonly used unit in the National Climate Change Process.